# STUDIES ON ROOT-KNOT NEMATODES INFESTING PIGEONPEA AND ITS INTEGRATED MANAGEMENT

**Thesis**

submitted for the award of the degree of

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**(Plant Protection)**


Submitted by

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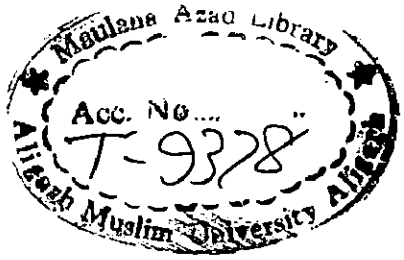


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## CERTIFICATE

This is to certify that Mr. Tarique Hassan Askary has worked on a problem entitled, "**Studies on root-knot nematodes infesting pigeonpea and its integrated management**" jointly under my supervision (Supervisor) and under the co-supervision of Dr. S. S. Ali, Indian Institute of Pulses Research, Kanpur, India (Co-Supervisor).

I have received three copies of his Ph. D. thesis on the above topic from the Chairman, Department of Plant Protection, AMU, Aligarh for my necessary ceritification. I have not gone through the Results and Discussion of this thesis before its submission by Mr. Askary to the Chairman, because of his prolonged absence from the department (20.8.2006 to date). However, I shall have no objection, if this thesis is forwarded for evaluation.

I wish Mr. Askary good luck.

December 1, 2008

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# Chapter-1

# INTRODUCTION

Pulses own a strategic position in intensive as well as subsistence agriculture, as they are an excellent source of dietary protein for millions of people, nutritious feed for livestock, and a mini-nitrogen factory having profound ameliorative effect on the soil. They play an equally important role in rainfed and irrigated agriculture by improving physical, chemical and biological properties of soil and are considered excellent crops for natural resource management, environmental security, crop diversification and consequently for viable agriculture.

Pulses constitute an important ingredient in the vegetarian diet in India and a major source of protein (21.1%), carbohydrate (62.5%) and fat (4.5%). They are rich in calcium, iron and some essential amino acids. Despite being the largest producer of pulses in the world, there is a short supply of pulse food. During 2005-06, pulse production in the country was 13.11 million tons from 22.47 million hectare area with an average yield of 600-650 kg/ha. This is below the domestic requirement, as a result around 1.6 million ton pulses were imported during 2005-2006 in India. In the current year, 2007 the import has already crossed 1.7 million tons in the first nine months (Ali and Kumar, 2007).

Among different pulse crops, pigeonpea, *Cajanus cajan* (L.) Millspaugh, is the most versatile food legume with diversified uses as food, feed, fodder and fuel. It is well adapted to tropical and sub-tropical conditions. Because of its drought tolerance and deep root system, it grows very well in the semi arid zone. It has been recognized as a valuable source of protein particularly in the developing countries where majority of the population depends on the low-priced vegetarian food to meet the dietary requirements. Its significance is comparatively more among Indians due to their reliance on vegetarian food besides limited buying capacity of more than 27% people who live below the poverty line. Like any other pulses, supplementation of pigeonpea with cereal-based diets is considered one of the possible solutions to alleviate protein energy malnutrition.

Pigeonpea plays an important role is sustaining soil productivity by fixing atmospheric nitrogen (Kumar Rao and Dart, 1987). The residual effect of the biologically

fixed nitrogen on a following cereal crop can be equivalent to 40 kg N/ ha (Nene, 1987). Pigeonpea produces more nitrogen from plant biomass per unit area of land than any other legumes although it usually produces fewer nodules (Onim, 1987).

Pigeonpea is a rich source of proteins, carbohydrates, and certain minerals (Gopalan *et al.*, 1971) containing 17.9 - 24.3 g protein/100g for whole grain samples, and 21.1 - 28.1/100g for split grains (Salunkhe *et al.* 1986) and calcium, phosphorus, magnesium, iron, sulphur, potassium and soluble vitamins, especially thiamin, riboflavin, niacin and choline in higher amounts.

Pigeonpea is the fourth most important pulse crop in the world with almost all production confining to developing countries in Asia. Globally, it is grown on about 4.16 million hectare land that yields 2.85 million tons grains with average productivity of 686 kg/hectare. Asia produces 2.56 million tons grains from 3.71 million hectare area with 691 kg per hectare productivity. Besides, it is also grown in North and Central America, South America and Africa. As many as 50 countries are reported to grow pigeonpea with major contribution (99%) coming from just six nations, *viz.*, India, Myanmar, Malawi, Uganda, Tanzania and Nepal.

It is considered an important grain legume in the semi-arid tropics with about 90% of the world production in the Indian subcontinent, principally in northern, central and eastern India (Nene and Sheila, 1990). In India, during 2004 – 05, pigeonpea was grown on about 3.51 million hectare area with 2.34 million tons of production which represent 14.4 and about 15.5% of the national pulse acreage and production, respectively. Pigeonpea is the second most important pulse crop in India. The states of Maharashtra, Uttar Pradesh, Karnataka, Gujarat, Madhya Pradesh and Andhra Pradesh are major producers of this pulse and contribute 83.3% of the national production from 86% of the area. Maharashtra alone accounts for 35.5% of the production from an area of 31.4%. During 2005–06, pigeonpea production and productivity in Uttar Pradesh was around 3.8 lakh tons (from3.8 lakh hectare) and 961 kg/ha, respectively.

The major constraints in the production of pigeonpea are insect pests and the diseases caused by viruses, fungi and plant parasitic nematodes. Nematodes have emerged as potential threats to pigeonpea production in the country. Numerous plant parasitic nematodes have been recorded from the rhizosphere of pigeonpea plants (Nene *et al.*,

1996). Among them, root knot nematodes (*M. incognita* and *M. javanica*), pigeonpea cyst nematode (*Heterodera cajani*), reniform nematode (*Rotylenchulus reniformis*) are potential nematode parasites in different pigeonpea growing areas (Sharma *et al.*, 1992). Nematode parasitism may directly affect plant growth and also reduce the formation of rhizobial nodules in the root system (Mohanty and Padhi, 1987). The plant parasitic nematodes cause an estimated annual loss of over 13% in pigeonpea yield (Sasser and Freckman, 1987; Sharma *et al.*, 1992). In India root-knot nematodes, *Meloidogyne incognita* and *M. javanica* are the most important nematodes of pigeonpea and cause considerable yield loss (14-29%) to the crop (Ali, 1987; Sharma *et al.*, 1993; Sharma *et al.*, 1996). In two pigeonpea cultivars *viz.*, Bahar and UPAS 120, the yield loss was estimated 10-18% due to root-knot nematodes (Khan, 2003)

Pigeonpea is also infected by numerous fungi and develop different diseases. Wilt caused by *Fusarium udum* is one of the important fungal diseases and are considered as another major constraint in pigeonpea cultivation. The incidence of the wilt has been recorded 1-10% (UP), 10-20% (Bihar) and 20% or more (Maharashtra) (Kannaiyan *et al.*, 1984). In India. The annual monetary loss to pigeonpea due to the wilt has been estimated worth of US $ 36 million (Kannaiyan *et al.* 1984). The yield loss depends on the stage at which plants wilt; the loss can be 100% if disease develops at pre-pod stage, about 67% and 30% when wilt occurs at maturity and pre harvest stage, respectively (Kannaiyan and Nene, 1981). The disease complex involving species of *Fusarium* and *Meloidogyne* is one of the most commonly occurring and destructing diseases pulse crops (Francl and Wheeler, 1993). Many researchers have demonstrated definite role of root-knot nematodes, especially *M. incognita* and *M. javanica* in the wilt of pigeonpea (Salam and Khan, 1986). Association of root-knot nematodes not only aggravates the wilt severity but also breaks the resistance of cultivars against the fungus (Webster. 1985). Dwivedi *et al.* (1992) reported that pigeonpea plants inoculated with *M. incognita* and *F. udum* simultaneously exhibited suppression in the plant growth greater than the plants inoculated with *F. udum* alone. Marley and Hillocks (1996) reported that wilt resistant cultivars of pigeonpea became susceptible to *F. udum* in the presence of *M. incognita* and *M. javanica.* Presence of *M. javanica* increased the susceptibility of six cultivars of pigeonpea to *F. udum* and suppressed the bacterial nodulation (Salam and Khan, 1986). Presence of *M. javanica* can break resistance in some of the pigeonpea cultivars resistant to *F. udum* whereas some of the resistant genotypes are not affected due to presence of the nematode

(Singh *et al.*, 2004). In sequential inoculation of *M. incognita* and *F. udum* on pigeonpea, maximum effects on plant growth were observed where nematode and fungus were inoculated simultaneously (Perveen *et al.*, 1999).

In order to fulfill the requirement of rapidly expanding population a continuous increase in pulse production is needed. To achieve such a difficult target besides using high yielding varieties and providing optimum inputs, proper management of disease is necessary. Various options are available which are used by growers as per the situations. But none of the methods provide satisfactory control of the disease. At the present state of knowledge, chemical pesticides are the best and reliable options but they pose serious health and environmental hazards, which have limited their use. Some effective biocontrol agents of root knot nematode and wilt fungus have been developed but their action is relatively slow and dependent of environmental factors. Under this situation, an integrated approach consisting of a lower dose of pesticide in conjugation with bio pesticides coupled with appropriate cultural practice is essentially needed to develop an economically viable and ecologically sustainable management of wilt, root-knot and disease complex of pigeonpea in India. To achieve these objectives following experiments were conducted.

1. To study the pathogenicity of root-knot nematode *M. incognita* on pigeonpea germplasm.

2. To study the pathogenicity of *F. udum* on pigeonpea germplasm.

3. To study interactive effects of the wilt fungus (*F. udum*) and root-knot nematode (*M. incognita*) on pigeonpea germpasm under pot condition.

4. To study interactive effects of the wilt fungus (*F. udum*) and root-knot nematode (*M. incognita*) on pigeonpea germpasm under field condition.

5. To devise and test an appropriate module for integrated management of wilt fungus and root-knot disease complex in pigeonpea.

# Chapter-2

# REVIEW OF LITERATURE

Pulses are a major source of protein for vegetarian masses throughout the world. In addition, they provide cholesterol free diet that suits to all kinds of consumers. Supplementation of cereals with pulses provides the best solution to alleviate protein-calorie malnutrition. Pulses are endowed with a noble trait of biological nitrogen fixation in association with rhizobia, which helps in sustaining soil fertility. They can fix huge amount of nitrogen through symbiosis and thus minimize dependency on synthetic fertilizers. In fact, inclusion of pulses in cereal based cropping systems has been viewed as a long term investment in resource enhancing technologies and as a component of integrated nutrient management.

India is the largest producer and consumer of pulses in the world accounting for 25% of the global production and 27% consumption. The domestic demand and consumption, however, is much higher than production due to growing preference towards vegetarian diets as pulses are the chief source of protein and provide high biological value when supplemented with cereals. In pulses, crude protein content varies from 17-34%, carbohydrates 57-60%, fat 2-3% and minerals 2-4%. In addition, pulses are rich in vitamin B, thiamine and niacin (Wijeratne and Nelson, 1986). The cereal-pulse diet recommended by the Indian Council of Medical Research is 400 g of cereals and 60g of pulses (approximately 7:1 ratio). Pulses when supplemented with cereals are known to improve overall nutritive value of the proteins in the mixed diet since pulses contain high amount of lysine (7.2%), an essential amino acid in which cereals are deficient (3%).

Besides their high nutritional value, pulse crops have a unique characteristic of restoring soil fertility through biological nitrogen fixation. These crops have a unique position in crop rotation, intercropping and crop diversification. Their cultivation economizes nitrogen to the tune of 30-40 kg/ha for succeeding cereal crop and also improve soil health. Thus pulses have a vital role in improving soil health and ensuring environmental security.

The country produces a variety of pulses including chickpea (40%), pigeonpea (18%), urdbean (11%), field pea (5%) and others totalling to the tune of 13-15 million tons annually from an area of 22-23 million ha with an average yield of 600-650 kg/ha (Ali and Kumar, 2007). India accounted for 72% of chickpea and 90% of pigeonpea global production during 2003. Chickpea and pigeonpea together account for 46% of cultivated area and 58% of the total production of pulses in India (Singh and Singh, 2007). The major pulse producing states are Madhya Pradesh (23%), Uttar Pradesh (18%), Maharashtra (14%), Rajasthan (11%), Andhra Pradesh (9%) and Karnataka (6%), where pulses are predominantly grown as rainfed crops. Domestic production of pulses after its peak of 14.94 million tons in 2003-04 had declined to 13.38 million tons in 2004-05 and to 13.11 million tons in 2005-06 due to adverse climatic conditions prevailed in the major production zones (Ali and Kumar, 2007).

The import of pulses had fell from 1008 thousand tons in 1997-98 to 350.57 thousand tons in 2000-01, but it rose to the maximum of 2232.29 thousand tons in 2001-02. The import of pulses fell down to 1296.46 thousand tons in 2004-05. Recently in 2006-07, India has imported 1800 thousand tons of pulses (Singh and Singh, 2007).

India, at present is facing an estimated shortage of 3.2 million tons of pulses. To meet this shortage pulses are imported from Myanmar, Canada, Turkey, Australia, France and Tanzania.

Though India has achieved food security, nutritional security continues to be a cause of concern. Presently population is growing by 1.6% annually, adding 16 million people every year to the already over 1 bilion population in India. More than 50% of the children under the age of 4 years are malnourished and 30% of new born are significantly underweight. The urgency thus is to break the yield plateau for rapid gains in pulse production to maintain pace with the population growth. It is estimated that the population of the country would be touching nearly 1350 million by 2020 A.D. and the minimum pulses requirement would be around 30.3 million tons which is more than double of the present production. Thus, there is an urgent need to strenghthen the pulses research, development and transfer of improved technology to the growers to meet the increasing demand of protein and attain self sufficiency in pulse production.

## 2.1 Pigeonpea production in India

Pigeonpea, *Cajanus cajan* (L) Millspaugh is an important pulse crop in India. Its every plant part has its own significance like roots fix nitrogen and improve physical properties of soil; stem is used as fuel, for making baskets and roofs of huts; leaves and pod walls are used as animal feed and manure; grains are rich source of protein (21%) and are used as dal, and immature green seeds and pods are used for vegetable. It is quite hardy and widely adaptable crop. The short duration (100-140 days) cultivars are cultivated as sole crop in the intensive cropping system of north India, while the medium duration (160-180 days) and long duration (>200 days) land races and cultivars are well suited as intercrop or

mixed crop with other crops in the central and southern India (Sandhu *et al.*, 2007). It also grows well on mountain slopes and checks the soil erosion.

Pigeonpea is grown extensively in India with current production of 2.43 million tons from 3.30 million ha land (Singh *et al.*, 2006). During the last five decades, area under pigeonpea cultivation has increased, however, the productivity has been hovering around 600-700 kg/ha. The production of pigeonpea in India has gone up from 1.88 million tons in 1970-71 to 2.37 million tons in 2003-04. During this period, the area had increased from 2.66 million ha to 3.52 million ha, but the productivity declined from 709 kg/ha to 672 kg/ha. Pigeonpea is the second most important pulse crop in the country with production base concentrating in Maharashtra (0.66 million tons), Uttar Pradesh (0.50 million tons), Karnataka (0.26 million tons), Madhya Pradesh (0.23 million tons) and Gujarat (0.10 million tons). Due to shortage of pulse, India had to import 354.17 thousand tons pigeonpea valued at US $ 100.77 million in 2001-02 mainly from Myanmar. India also exports small quantities of pigeonpea mainly to UAE, USA, UK, Kuwait and Malaysia. India's exports of pigeonpea decreased from 9.087 thousand tons, valued at US $ 5.44 million in 2001-02 to 8.179 thousand tons valued at US $ 4.99 million in 2002-03.

## 2.2 Uses of pigeonpea

Pigeonpea is most widely eaten in the form of split grains. Dry seeds are also consumed as snacks after being boiled in water. Green pods and green seeds are also consumed as a vegetable. Vegetable pigeonpea types are important in Central America as well as in Western and Eastern Africa, where green peas are consumed as soups (Morton, 1976). Vegetable types, generally large podded with sweet-tasting green seeds are preferred in Puerto Rico. Canned pigeonpeas are marketed in certain parts of the world (Morton, 1976).

By-products of split and shriveled grains are used as livestock feed. The present high cost of animal sources of protein feeds such as fish and bone meal makes pigeonpea ideal to be used as a good plant protein substitute as it is less expensive. Pigeonpea provides excellent forage for livestock and there is a great scope for selecting cultivars with higher yields of grains, forage and crude protein. It has a high percentage of crude protein (28.2 - 36.7%). Wild species of pigeonpea have been found to be promising sources of high protein. Several high protein genotypes have been developed with protein content as high as 32.5% (Singh *et al.,* 1990). The high protein genotypes contain, on an average, 20% greater protein than the normal genotypes (Reddy *et al.,* 1979; Saxena *et al.,* 1987). The high protein genotypes also contain significantly higher (about 25%) sulphur containing amino acids, viz., methionine and cystine (Singh *et al.,* 1990). Pigeonpea seeds also contain about 57.3-58.7% carbohydrate, 1.2-8.1% crude fiber, and 0.6-3.8% lipids (Sinha, 1977). Calcium, phosphorus, magnesium, iron, sulphur, potassium and soluble vitamins, especially thiamine, riboflavin, niacin and choline are also in adequate amount.

Pigeonpea being a legume crop fixes nitrogen in the soil. The leaf fall at maturity not only adds organic matter to the soil, but also provides additional nutrition. In a cropping sequence where maize followed pigeonpea, residual nitrogen was estimated to be approximately 40 kg/ha (Kumar Rao *et al.,* 1981).

Pigeonpea is tolerant to drought as it has a deep root system which enables in breaking the plough pan resulting in an improvement in soil structure. That is why pigeonpea is often called as a biological plough.

## 2.3 Diseases of pigeonpea

Amongst the various abiotic and biotic constraints, diseases are one of the most important yield limiting factor in pigeonpea. The crop is considered risky, mainly due to

proneness to diseases caused individually or simultaneously by fungi, bacteria, viruses and nematodes. Pigeonpea can be attacked by more than 100 pathogens (Nene *et al.,* 1989), however a few cause losses of economic value (Kannaiyan *et al.,* 1984). In the Indian subcontinent and eastern Africa, wilt caused by *Fusarium udum* is supposed to be the most important disease of pigeonpea (Nene and Reddy, 1981). Another prevalent disease is root-knot caused by *Meloidogyne* spp. (Khan, 2005).

## 2.4 Root-knot nematodes, *Meloidogyne* spp.

Plant parasitic nematodes cause significant damage to pigeonpea crop, however, due to their covert nature of damage, microscopic size, subterranean habitat, they are usually successful in evading the attention of growers and plant protection practitioners. Many species of plant parasitic nematodes have been found associated with pigeonpea (Nene *et al.,* 1996). In total sixty five species in 24 genera of nematodes from 24 countries have been found associated with pigeonpea roots (Nene *et al.,* 1989). Of these *Meloidogyne* sp., *Pratylenchus* sp., *Heterodera* sp., *Rotylenchus* sp. and *Helicotylenchus* sp. are considered important. The major nematode pests are *Meloidogyne* (*M. incognita* and *M. javanica*), *Heterodera cajani* and *Rotylenchulus reniformis* (Sharma *et al.,* 1992). These nematodes may directly affect the physiological functioning of the plants to an extent of producing a lower yield.

The root-knot nematodes, as the name suggests cause galls or knots on the roots. The root-knot disease was first reported on the glass house grown cucumbers in England by Berkeley (1855) who named the nematode as 'Vibrios'. Cornu (1879) named this nematode as *Anguillulla marioni*, Muller (1884) as *Heterodera radicicola* and *Goeldi* (1887) as *Meloidogyne exigua.* Goodey (1932) reviewed the status of root knot nematodes and preferred to call them *Heterodera marioni.* Finally Chitwood (1949) upheld the

nomenclature given by Goeldi, and transferred the nematode to the genus *Meloidogyne* from *Heterodera*.

## 2.5 Economic importance

Crop losses causes by the root knot nematodes are generally serious in subsistence agriculture particularly in areas that are cropped for a long time. The most serious damage occurs to roots, which is difficult to diagnose by foliar symptoms. Almost all the plants that account for the majority of the world's food supply are susceptible to infection by root-knot nematodes. Although average field losses have been estimated at 5% but poor farmers particularly in the developing countries suffer much greater damage (Swarup *et al.*, 1989). *M. incognita, M. javanica, M. arenaria* and *M. hapla* are the four major species of root-knot nematodes which attack an array of agricultural crops and reduce their productivity. Realizing the importance of root knot nematodes in 1975, the United States Agency for International Development (USAID) founded a project at North Carolina State University, USA, entitled "Research on Integrated Crop Protection Systems" with emphasis on the root-knot nematodes (*Meloidogyne* spp)." Later International *Meloidogyne* Project (IMP), Crop Nematode Research and Control Project (CNRCP) were introduced with the involvement of more than 60 countries in the world.

## 2.6 Distribution

### 2.6.1 World Scenario

To date 96 species of root-knot nematodes have been reported from different countries (Ganguly, 2002). Four species, M. *javanica* (Treub, 1885), *M. incognita* (Kofoid and White) Chitwood 1949), *M. arenaria* (Neal, 1889) and *M. hapla* (Chitwood, 1949) have been recognized as major species of root knot nematodes. *M. incognita* and *M. javanica* being widely distributed in tropical and subtropical areas and *M. hapla* being restricted to

temperate areas of the world (Swarup *et al.*, 1989). *M. incognita* and *M. javanica* have been reported to attack pigeonpea in Australia, India, Pakistan, Malawi, Nepal, Trinidad and USA; *M.javanica* in Brazil, India, Pakistan, Peurto Rico, Zambia and Zimbabwe (Reddy *et al.*, 1990).

Analysis of responses received from 40 cooperators in 20 countries to a questionnaire on nematode problems of groundnut, pigeonpea, chickpea, sorghum and pearl millet that *Meloidogyne* spp. are internationally important nematode pests of pigeonpea, groundnut and chickpea (Sharma and Mc Donald, 1990). Another study on the distribution of plant parasitic nematodes in different agroecological zones representing the major pigeonpea producing regions in north eastern Kenya revealed that *M. javanica*, *Scutellonema unum* and *Rotylenchulus parvus* are potentially important species associated with pigeonpea (Sharma *et al.*, 1993). Out of the decribed species of *Meloidogyne*, *M. incognita* with 4 races ($R_1$, $R_2$, $R_3$ and $R_4$), *M. javanica, M. arenaria* with two races ($R_1$ and $R_2$) and *M. hapla* have wide host range and distribution (Sasser, 1979, Khan *et al.*, 1988). Khan *et al.* (2003) has ascertained the existence of 2 races in *M. javanica* populations. The elaborated report based on 195 root samples collected from 9 districts in the state of Uttar Pradesh and Uttaranchal has demonstrated the presence of two races in *M. javanica* with the frequency of occurrence of 70% of race 1 and 30% race 2.

### 2.6.2 Indian scenario

In India, the occurrence of root-knot nematodes is available from most of the states and union territories in India (Khan and Khan, 1996). So far 14 species of root-knot nematodes have been described from India (Ganguly, 2002). Sitaramaiah (1984) listed 11 species viz., *M. incognita, M. javanica, M. arenaria, M. hapla, M. graminicola, M. lucknowica, M. acrita, M. brevicauda, M. africana, M. exigua* and *M. thamesi* occurring on a large number of plants in India. Later on two more species, *M. graminis* (Nayak *et al.*, 1986) and *M. triticoryzae* (Gaur *et al.*, 1993) were described. *M. acrita, M. thamesi* and *M. lucknowica* have now been synonymised with *M. incognita, M. arenaria* and *M. javanica* respectively (Eisenback and Triantaphyllou, 1991). *M. incognita* is present in almost all the states/union territories surveyed (Khan, 1997). *M. javanica* was found infecting an array of crops with almost equal frequency in Uttar Pradesh, Bihar, West Bengal, Haryana, Himachal Pradesh, Rajasthan, Kerala, Tamil Nadu and Delhi. *M. arenaria* has been reported from Uttar Pradesh, Bihar, West Bengal, Tamil Nadu and Delhi. In the hilly areas of Uttaranchal, Bihar, Tamil Nadu and Himachal Pradesh, *M. hapla* has been found associated with different crops. Khan (2005) conducted a survey in Nadia, West Bengal to determine the nematodes associated with pigeonpea, chickpea, peas, lentil and lathyrus. *M. incognita* was found to be one of the most dominant species among other plant parasitic nematodes associated with the crops.

On the basis of survey in various parts of India it has been found that root-knot nematodes (*M. incognita* and *M. javanica*) are serious pest of pulse crops in most parts of the country (Ali, 1995). Ali (1991) reported that root-knot, reniform and lance nematodes were predominant in Aligrh, Agra, Bulandshahar, Ghaziabad, Kanpur and Mathura districts of Uttar Pradesh. Sharma *et al.* (1996) examined soil and root samples for plant parasitic nematodes from 171 pigeonpea field in 32 districts of Uttar Pradesh and found that *M.*

*incognita* and *M. javanica* were present in moderate to high number. Ali and Sharma (2002) performed random surveys in chickpea fields in Rajasthan and found infestation of root-knot nematodes *M. incognita* and *M. javanica* is sandy soils of Jaipur, Jhunghunu and Swai Madhaopur.

Ali and Askary (2001) reported that along with *Heterodera cajani, M. incognita, M. javanica* and *R. reniformis* are serious pests of pigeonpea and are widely distributed in Andhra Pradesh, Karnataka, Uttar Pradesh, Gujarat, Maharashtra and Madhya Pradesh. They also identified *M. incognita* and *M. javanica* as key pests of other pulse crops *viz.*, lentil, field pea, rajmash, lathyrus, cowpea and rice bean. Recently Ali and Pervez (2007) assessed the distritbution, abundance and frequency of plant parasitic nematodes prevailing in pigeonpea and chickpea ecosystems at Hamirpur district, Uttar Pradesh. Altogether 68 soils samples collected from pigeonpea rhizosphere yielded eight species of plant parasitic nematodes including root-knot nematode *M. javanica.*

## 2.7 Race distribution

In India establishment of identity of species and races of root-knot nematodes and their distribution have not got adequate attention. However, some work has been done on the differentiation and distribution of races of *M. incognita* and *M. arenaria* (Krishnappa, 1985; Khan, 1997). Information on races indicates existence of all four races of *M. incognita* in India. Krishnappa (1982) by examining root-knot nematode in Karnataka, Madya Pradesh, Andhra Pradesh and Tamil Nadu found that *M. incognita* was invariably present in all the samples studied. Race 1 was dominant followed by race 2 and race 3. Krishnappa and Setty (1983) reported the occurrence of race 1 and race 3 from Karnataka. Bajaj *et al.* (1986) found all the four races of *M. incognita* from Haryana. Occurrence of races 1 and 2 have been reported in four districts *viz.*, Patna, Muzaffarpur, Samastipur and

Darbhanga of Bihar (Haider *et al.*, 1988) and race 3 from Pune in Maharashtra (Darekar *et al.*, 1988). Khan *et al.* (1988) and Khan and Khan (1991) identified host races in *M. incognita* and *M. arenaria* populations from Uttar Pradesh. They showed the existence of all the four races of *M. incognita* and race 2 of *M. arenaria*. In overall assessment based on results of studies in Uttar Pradesh (Khan, 1988; Khan and Khan, 1991, 1992; Khan *et al.*, 1993,1994), occurrence of race 1 in *M. incognita* populations was highest closely followed by race 2. Race 4 was third most frequent race while race 3 was least frequent. Race 2 of *M. arenaria* has been recorded from Bihar, Assam, Haryana, Himachal Pradesh, Karnataka, Maharashtra, Orissa and Tamil Nadu. Recently Khan *et al.* (2003) reported the existence of 2 races in *M. javanica* populations. The report was based on the root samples collected from Uttar Pradesh and Uttaranchal. The frequency of race 1 was 70% whereas race 2 was 30%.

## 2.8 Host range

Root-knot nematodes, *Meloidogyne* spp. are most dreadful nematodes infecting vegetables, pulses, fruits, ornamentals, oilseeds and fibre crops in different parts of the country (Patel and Patel, 2002). *M. incognita* and *M. javanica* have the widest host ranges, covering over 232 and 144 genera of plants, respectively.

The most preferred hosts are tomatoes, brinjal, okra, potato, chillies, carrots, cuccurbitis, beans among vegetable crops; grapes, papaya, peach, mulberry, pomegranate among fruit crops; chickpea, pigeonpea, mungbean, black gram, green gram, pea and lentil among pulse crops; cotton and jute among fibre crops; groundnut and sunflower among oilseed crops; ginger, pepper, turmeric, tea, coffee among plantation crops; and ornamental plants in different parts of India (Singh and Gill, 1989). *M. hapla* has been encountered in areas of Jammu and Kashmir, Himachal Pradesh and hilly areas of Assam where it is a problem on ornamental plants, potato and tea, respectively. *M. arenaria* is a serious problem

of groundnut in Gujarat. Other locally important species are *M. graminicola* on rice in eastern states, *M. brevicauda* on tea in Assam and *M. exigua* on coffee in Karnataka (Walia and Bajaj, 2001).

## 2.9 Disease symptoms

The symptoms caused by the root-knot nematodes are very much similar to nutrient deficiency symptoms. The apparent symptoms on foliage are stunting, smaller size of leaves and fruits, chlorosis and patchy growth in severe cases. The leaves may dehiscent prematurely. Pods may ripe and dry prematurely and remain partially filled and undersized (Reddy *et al.*, 1990). A mild wilting in foliage may be observed during the period of high transpiration rate (Southey, 1978). Poor emergence and death of young seedlings may occur in heavily infested soil, but death of grown up plants is rare unless some fungus or bacteria become associated and form a disease complex (Francl and Wheeler, 1993).

The discernable and most characteristic symptom of root-knot nematode infestation is formation of gall on the plant roots (Bird, 1972). The galls vary in size and shape, depending on the species and population density. The small galls on the roots may become large in size in the event of multiple infection. Due to gall formation legume plants exhibit reduction in the number (Gupta *et al.*, 1986; Khan, 2003) and size of rhizobial nodules (Nath *et al.*, 1979). The rhizobium, however, does not interfere with the activity of nematodes whereas, the nematode has harmfull effect on rhizobium (Taha, 1993).

## 2.10 Causal organism

Root-knot nematode, *Meloidogyne* spp. is a sedentary endoparasite and second stage juveniles are infective stage of the nematode. Male and female larvae penetrate host roots. The females become sedentary after getting suitable site for feeding and gradually assume obesity. Male larvae do not feed and remain or become vermiform and migrate out of root at

maturity. Females at maturity lay hundreds of eggs, on average 200-500 in a gelatinou matrix collectively called as an egg mass. Reproduction is parthenogenetic and life cycl from egg to egg completes in around three weeks. The species of root-knot nematode *M incognita* and *M. javanica* which have been found associated with pigeonpea can b differentiated on the morphology of perineal pattern, female stylets, male heads and stylets and second stage juveniles (Eisenback, 1985).

**2.10.1** ***Meloidogyne incognita***

The juveniles have a dumbelled shape labial disc and medial lips view. The labia disc is small and slightly raised above the median lips. Lateral lips lie in counter with th head region. Body length, 346-463 (405) µm; tail length, 42-62 (52) µm; head end to styl base, 14-16 (15) µm; female stylet length, 15-17 (16) µm; male stylet length, 23-25 (24) µm Mature female: The medial lips are wider than labial disc, but both are dumbelled shape Under SEM two bumps may appear on the ventral side of the labial disc. Lateral lips ar large and separated from the rounded medial lips. Stylet cone is distinctly curved dorsall The anterior portion of the cone is cylindrical, whereas the posterior part is conical. Th shaft is slightly wider at posterior side. The knobs are broadly elongated and set-off fro the shaft, and indented anteriorly so much that in some specimen each knob appears as tw Mature male: Head shape is very characteristic and not easily confused with any oth species. The labial disc is large and round. It is ventrally curved and raised above medi lips. The median lips are as high as the head region. There are 2-3 incomplete annulatio on the head region. Stylet tip is blunt and wider than the medial portion of the cone. Lume of the stylet opens with a projection on the ventral side, which is located one fourth distanc of the cone length from the stylet tip. The shaft is cylindrical and tapers near the knobs. Th knobs are set-off from the shaft. They are broadly elongate to round and are indente anteriorly.

### 2.10.2 *Meloidogyne javanica*

Second stage juveniles: The labial disc and medial lips are bow-tie shaped. The lateral lips are triangular and lie below the contour of the labial disc and medial lips. Occasionally head region has short annulations, but generally it is smooth. Body length, 402-560 (488) µm; tail length, 51-63 (56) µm; head end to stylet base, 14-16 (15) µm; female stylet length, 14-18 (16) µm; male stylet length, 18-22 (20) µm. Mature female: The medial lips and labial disc are dumbbell shaped. The labial disc two prominent bumps ventrally. Usually lateral lips indented and they are large, elongated and set-off from medial lips and head region. The head region may be marked by one incomplete annulation. Stylet is similar to *M. incognita* except that the cone is not distinctly curved dorsally and gradually increases in width posteriorly. The shaft widens only slightly posteriorly and knobs are short and wide, often anteriorly indented. Mature male: Head cap is high and almost as wide as the head region. The labial disc and median lips are large and fused together. The head region is annulated (2-3 annules) in some population, whereas in others annules are absent. Stylet cone is narrow anteriorly, but very wide posteriorly. The shaft is cylindrical and often narrows near the junction of stylet knobs. The stylet knobs are low, wide and set-off from the shaft.

## 2.11 Perineal patterns

The outer cuticle of saccate females at maturity becomes smooth and transparent on most of the body except posterior part around vulva. The transverse striae and lateral lines which disappear from the main body due to obesity remain prominent and distinctive together with phasmids and appear as a finger-like structure called as perineal pattern. The pattern shows fare degree of uniformity within a species. Identification through perineal pattern is more useful when a species is to be identified from the infected root samples. Preparation of pattern does not take much time compared to picking and mounting of a

larvae, but sometimes it may involve some confusion. Important diagnostic characters of the two species of root-knot nematodes are as follows:

### 2.11.1 *Meloidogyne incognita*

The pattern is characterized by the presence of high and squarish dorsal arch. The arch may contain a distinct whorl in tail terminus area. The striae are smooth to wavy and sometimes zigzagged. Distinct lateral lines are absent, but the lateral field may be marked by breaks and forks in the striae. Some striae may bend towards vulva.

### 2.11.2 *Meloidogyne javanica*

The perineal pattern is unique because it contains lateral lines, which divides the dorsal and ventral striae. The ridges run entire width of the pattern, but gradually disappear near the tail terminus. The dorsal arch is low and rounded to high and squarish. The striae are smooth to slightly wavy, and some striae may bend towards vulval edges.

## 2.12 Life cycle and disease development

Saccate females are sedentary endoparasites and are completely embedded inside the root galls. Reproduction is parthenogenetic and eggs are deposited by female in the gelatinous matrix secreted by rectal glands which is generally found on the surface of the galled roots. Oviposition continues for 10-12 days, each female lays about 200-500 eggs held together in an egg sac. Following embryogenesis the first moult occurs within the egg giving rise to a second stage juvenile ($J_2$). Depending on the availability of the suitable temperature and moisture, $J_2$ hatches out, moves freely in soil in search of new roots of the same plant or some other plant and is the only infective stage. Under normal conditions $J_2$ can remain in soil for several days, deriving energy from reserve food material. However, under adverse environmental conditions, $J_2$ can survive in soil for several months in an inactive anhydrobiotic phase (to cut down metabolism) when the body shrinks and coils (Walia and Bajaj, 2001).

Initially, juveniles ($J_2$) move in soil randomly but when it has received chemical stimuli through root exudates from a susceptible plant its movement becomes faster and oriented (Southey, 1978). The juveniles penetrate roots just behind the root tip (meristematic zone). Penetration is facilitated by repeated stylet thrusts and/or enzymes secreted by the nematodes oesophageal glands. After penetration, $J_2$ move intercellulary in the root cortex and position themselves with head located near vascular tissues, while rest of the body is completely inside the cortex. Larvae do not feed until it is completely inside living plant tissues and the mobility of the nematode becomes limited to head movement and nematode starts feeding usually on pericycle cells. The cell contents are liquefied and semi digested extra corporeally with the help of hydrolytic enzymes secreted by oesophageal glands. The nematode enzymes induce excessive conversion of tryptophan into indole acetic acid (Dasgupta and Gaur, 1986). This results into enlargement (hypertrophy) of infected root tissue and formation of multinucleated giant cells (2-6) around the nematode's head in steler tissue (Bird, 1962; Haung, 1985; Pasha *et al.,* 1987). The gaint cells are formed due to repeated endomitosis without cytokinensis of primary phloem cells or adjacent parenchyma and pericycle cells (Hussey, 1989; Wiggers *et al.,* 1990; Haung, 1985; Pasha *et al.,* 1987). The cortical parenchymatous cells around the giant cell undergo excessive multiplication (hyperlesia) giving rise to tiny swellings on the roots or primary galls (Loewenberg *et al.,* 1960), several of which may merge into big multiple galls. The degree and size of galling depends on the species of nematode, host plant and the number of nematodes present. Root tips may become devitilized and the growth is ceased. The juveniles continue to feed on giant cells for a period of several weeks optionally. During this period $J_2$ start assuming obesity. Second moult occurs giving rise to $J_3$. The third moult follows quickly and juvenile develop to $J_4$. sex differentiation occurs after third moult. Female acquire V-shaped genital primordium, while in males, it is I-shaped. The $J_3$ and $J_4$

retain the old cuticles as a result of superimposed moult. The pointed tail of $J_2$ still visible and hence are also called spike tailed stages (Haseeb, 2002). $J_3$ and $J_4$ are non-feeding stage as they lack stylet. At the last moult, adult female becomes sac like, stylet reappears and the reproductive system gets fully developed with vulval opening making its appearance. Adult males become vermiform, coiled inside $J_4$ cuticle, emerge out and migrate out of root into the soil. They are short lived. The length of life cycle and number of generations depends on host health and temperature. Optimum temperature for *M. incognita* and *M. javanica* is 25-30°C. The life cycle of these species completes in 21-25 days at 26-27°C and in 50-60 days or even 80 days at 14-16°C. In general, the temperature of 25-28°C and light textured soil are best for rapid multiplication, larval movement, infection and gall formation.

The second stage juveniles (infective stage) inject secretions from oesophageal glands which lead to several physiological and morphological changes in the invaded tissue, paramount significance are giant cells (Bird, 1972). Concurrent with the establishment of giant cells, root tissue around the nematode and its feeding site undergoes hyperplasia and hypertrophy leading to development of characteristic root galls which develop within two days of penetration and are often the first discernible symptoms of nematode infection (Khan and Esfahani, 1990). Formation of galls causes impairment of absorption of water and minerals by roots, subsequently the plant show water stress symptoms (Wallace, 1987). Upward conduction also decreases leading to accumulation of nutrients in root tissue (N, P, K, Mg etc). Water stress condition results in reduction in photosynthesis and increase in transpiration rate (Wilcox-Lee and Loria, 1987).

### 2.13 Yield loss

Information on relationship between population densities of root-knot nematodes and yield losses has revealed that *Meloidogyne* spp. are one of the major limiting factors to

pulse production. Pigeonpea grown in root knot nematode infested field can suffer significant damage. Root-knot nematode reduces the length and weight of plants, number of pods, bulk density of woody stem, chlorophyll content of leaves, root nodulation and water absorption capacity of roots (Alam *et al.,* 1991). Bridge (1981) has estimated 8-35% yield loss to pigeonpea due to root-knot nematode. In India the avoidable yield loss in pigeonpea cv. Pusa Ageti due to *Meloidogyne* spp. was assessed upto 14.2% in Gujarat state particularly in the field infested with a mixed population of *M. javanica* and *M. incognita* (Patel and Patel, 1993). Khan (2003) have reported 10-18% yield loss due to root-knot nematodes to two pigeonpea cultivars viz., Bahar and UPAS-120.

## 2.14 Pathogencity

Information on nematode tolerance level of crops has a great significance in agricultural production. It is known that there is a positive correlation between nematode population level and crop damage studies. Pathak *et al.* (1986) found a significant plant growth reduction in pigeonpea seedlings when an initial inoculum of 100 juveniles of *M. incognita* or *R . reniformis* was inoculated per plant in 500 g soil. However, in concomitant inoculations, root-knot formation and final populations of *M. incognita* were suppressed at all inoculum level in the presence of *R. reniformis.*

Mishra and Gaur (1987) studied the relation between individual and concomitant populations of *M. incognita* and *R. reniformis* on the growth of pigeonpea. The result showed that both the nematodes reduced shoot and root length, number of floral branches, pods and rhizobial nodulation at an inoculum level of 10 or more juveniles per pot both individually and in combination. Fresh weight of roots and shoots were significantly reduced at or about 100 nematodes individually or at 1000 and 10,000 levels concomitantly.

Tyagi *et al.* (1989) found a greater suppression in plant growth, pollen fertility and water absorption capability in pigeonpea cv. UPAS 120 than in cv. ICPL4 when inoculation of *M. incognita* and *R. reniformis* juveniles was done on plants under pot condition. Significant growth suppression was observed when plants were inoculated with 1000 juveniles per plant per pot. Patel *et al.* (2003) studied the effect of *M. javanica* race 2 and *H. cajani* on growth characters of pigeonpea under pot conditions. A significant decrease in plant height, fresh shoot and root weight was observed at inoculum level of 1000 and above $J_2$ per plant for *M. javanica* race 2 and above 100 $J_2$ per plant for *H. cajani.*

## 2.15 Management of root-knot disease

To reduce the losses caused by nematodes to pigeonpea, application of different management tactics is adopted depending on the feasibility. The purpose of management of a particular nematode is to reduce the nematode population to noninjurious level by applying multiple control procedures. The management of nematodes include the elements of preventing methods also so that the population are not built upto the damaging levels. Management strategies include following control methods.

## 2.16 Chemical control

Root-knot nematodes and other nematodes associated with pigeonpea spend part of their life cycle in soil, hence, to obtain effective control, the soil has to be disinfected. The use of chemicals become economical when other methods such as rotation are inadequate to suppress the nematode population sufficiently or the nematode population are very high and susceptible crop is to grow. Nematicides have been found to give quick and demonstrable control of nematodes, however, the large doses of nematicides are required for soil application that involves high costs, environment hazards and residue problem (Sethi and

Gaur, 1986). Despite having numerous adverse effects still nematicides are most effective mean of disease management (Johnson, 1985).

It was the DD mixture which helped to realize the importance of nematodes in agriculture and its commercial use stared in 1945. Since then, a number of nematicides have been developed under two category *viz.*, fumigants i.e., halogenated hydrocarbons and non fumigants i.e., organophosphates, carbonates etc. (Brown and Kerry, 1987). The fumigants are generally highly volatile compounds and when applied in the soil turn into gaseous phase. The vapours diffuse through the pore spaces and cause toxicity to nematodes. However, there are certain problems associated with the use of fumigants as they are generally phytotoxic. Some of them may need special applicators and plastic covers to prevent the escape of vapours into the atmosphere.

Contact and systemic nematicides come under non-fumigants which are widely used in agriculture. Ethoprop, Fensulfpothion, Phenamiphos, Phorate and Thionazin belong to organophosphate group whereas Aldicarb, Carbofuran, and Oxamyl comes under carbamate group. These chemicals have some advantages as they are effective at low dosages, easy to handle and apply, relatively non-volatile, mostly systemic and slow release in action (Walia and Bajaj, 2001). Nematicides are applied through different modes such as soil application (Jain and Bhatti, 1991), seed treatment, bare root dip treatment and nursery bed treatment (Bhatti and Walia, 1993). A few nematicides e.g., Fenamiphos can also be applied as foliar sprays as they are systemic and basipetal in action (Johnson, 1985). Nursery bed treatments with nematicides like carbofuran, aldicarb, fenamiphos etc are effective in reducing the root galling by 27-49% against *M. javanica* (Jain and Bhatti, 1991).

## 2.17 Soil application

Gupta and Verma (1992) reported that seed treatment with carbofuran at 1%+ soil application with phorate at 0.5 kg/ha gave best control of *M. javanica* on *Vigna radiata* under field condition, while yields were highest with carbofuran + phorate at 1 kg/ha. Application of chemicals *viz.*, carbofuran and phorate as soil treatment, seed dressing and spot application found effective to control *M. incognita* on peas under field condition (Sharma and Mathur, 1994). All treatments gave a significant decrease in the number of juveniles/g soil and root-knot index compared with control. In nursery plots Siddiqui *et al.* (1998) found that phorate and fenamiphos at 0.6 g a.i/$m^2$ and carbofuran at 0.3 g a.i/$m^2$ were effective in improving aubergine growth and reducing galls of *M. incognita* on roots.

## 2.18 Seed Treatment

Seed treatment with chemicals is a cheap and effective control measure of plant parasitic nematodes. An increase in the yield by 18.6% was observed when pigeonpea seeds were treated with monocrotophos. However, soil application of carbofuran @ 2 kg a.i./ha increased the yield of pigeonpea by 38% (Annon.,2001).

Seed soaking of blackgram (*Vigan mungo*) with fenamiphos, monocrotophos or acephate at 250, 500 or 1000 ppm for 12 hours have been reported to reduce the population of root-knot nematode (Baheti and Yadav, 1993). Seed dressing with chemicals viz., carbofuran, ethoprophos, phorate and diazinon have also been found reducing the effect of root-knot nematode on green gram (Borah and Phukan, 1990). Gupta *et al.* (1987) found that thimet (Phorate 10G) used under pot condition at 6% a.i. (w/w) as seed treatment was effective in reducing the formation of egg masses and in turn reducing the fecundity of *M. javanica* on mungbean. Carbofuran at the same concentration were similar to phorate in

reducing the number of galls or nodules on the plant but not as effective in reducing egg masses.

Soaking the seeds of cowpea cv. Co. 1 in carbosulfan at 0.1% and 0.05% for 6 hours before sowing, significantly minimized *M. incognita* penetration in roots, reduced the gall index and improved crop growth (Kumar, 1996). Monocrotophos at 0.1% was also found effective in increasing the yield. In a pot experiment, soaking of chickpea seeds with monocrotophos was more effective than carbosulfan in controlling the population of *M. incognita*. Similarly soil application of carbofuran at 2 kg a.i./ha was better in improving plant growth characters and reducing nematode population in comparison to sebufos and phorate.

Seed treatment with Furadan (2%) and Oncol (2%) eliminated root galling due to *M. incognita* in pigeonpea. The nematicidal seed treatment also reduced the rate of increase of nematode population in the soil by 45.2 to 70.6% (Mishra, 1986).

Fazal *et al.* (1996) tested five chemicals viz., carbofuran, diazinon, phorate, ethoprophos and subufos as seed treatment @ 0.5, 1.0 and 2% a.i. (w/w) for the control of *M. incognita* in green gram. All the chemicals resulted to a decrease in the population of nematode and gall development, with consequent increase in plant growth. The best result was obtained with carbofuran at 2% a.i. (w/w). Gupta and Verma (1992) reported that seed treatment with carbofuran at 1% + soil application with phorate at 0.5 kg a.i./ha gave best control of *M. javanica* on *Vigna radiata* under field condition, while yields were highest when soil application was done with carbofuran + phorate at 1 kg a.i./ha. Egg mass production and fecundity of *M. javanica* on *V. mungo* were effectively reduced with the application of 6% a.i. of phorate or carbofuran (Gupta *et al.*, 1987).

### .19 Cultural method

Cultural practices are one of the effective method of suppressing root-knot ematodes. However, these methods require little extra expense. Cultural method involves, allowing, flooding, summer ploughing, green manuring, soil solarization, adjustment of owing / planting time, crop rotation etc.

#### .19.1 Fallowing

When land is left uncropped after harvest, nematodes cannot survive in the soil in ıe absence of their hosts, except those that have good anhydrobiotic systems and structure Dasgupta, 2000). The practice of keeping the land free of vegetation for a certain period educes the number of plant parasitic nematodes as they get killed due to starvation Halbrendt *et al.*, 2004).

#### .19.2 Flooding

Plant parasitic nematodes which are normally associated with dry culture crops do ot infect their hosts in saturated soil. Flooding eliminates hosts and the nematode may die ue to deficiency of $O_2$. To get a soil rid of root-knot nematodes, 12-22 months of flooding p to 10 cm is necessary (Dasgupta, 2000).

#### .19.3 Summer ploughing

Two or three deep ploughings with a soil turning device, in hot summer months xposed the nematodes in soil and infected tissue to solar heat and dehydration resulted in ringing down the nematode population in soil. Ploughing in different seasons results in a ignificant decrease in nematode population in soil. However, deep ploughing proved more ffective than normal ploughing (Wani, 2005).

### 2.19.4 Green manuring

Green manures are rotation or cover crops that are ploughed back into the soil while still green and allowed to decompose. This process brings a drastic reduction of nematode population in soil. Germani and Plenchette (2004) used *Crotalaria* sp. as green manure which resulted in decreasing the level of root-knot nematodes. Fathi *et al.* (2004) incorporated tea dust residue @ 25 g /kg in the soil and found to be highly effective in suppressing root-knot nematode. Germani and Plenchette (2004) used *Crotalaria* sp. as green manure which resulted in decreasing the level of root-knot nematodes. Fathi *et al.* (2004) incorporated tea dust residue @ 25 g /kg in the soil and found to be highly effective in suppressing root-knot nematode. Effect of green manure, have also been reported by several workers to be found effective in reducing root-knot and other plant parasitic nematodes in soil (Litterick *et al.*, 2004; Berry *et al.*, 2005; Berry and Rhodes, 2006).

### 2.19.5 Soil solarization

The use of transparent polythene sheet to trap solar heat and disinfect soil from nematodes is usually considered most effective in hot, arid climates. Direct effect of temperature may have dramatic effects on nematode population in soil. Polythene mulching for soil solarization has also been found effective in reducing root-knot nematodes in soil (Sharma *et al.*, 2005).

### 2.19.6 Sowing / planting time

The infestation of root-knot nematodes can be reduced by late planting and early harvest of a crop. Escape cropping, planting crops early or late when temperatures are too high or low for nematode infection and development, has been used to reduce nematode damage (Bridge, 1996).

## 2.20 Crop rotation

A good or non-host crop rotation reduce nematode populations and increase yields (Rodriguez-Kabana and Ivey, 1986). Root-knot nematode densities may decline more quickly in soils after a single rotation crop (Halbrendt *et al.*, 2004). Crop rotation is likely to be very effective when the pathogen species or strain involved has a very limited host. Combined effect of cropping sequences and ploughing in different seasons resulted in a significant decrease in nematode population in soil (Wani, 2005).

## 2.21 Soil amendment

Soil amendment is any material added to a soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration and structure thus providing a better environment for roots. Soil amendments are used both in organic as well as inorganic form. The microbial decomposition of organic amendments into volatile fatty acids viz., formic, acetic, propionic and butyric acids, ammonia and hydrogen sulphide are directly toxic to nematodes. Changes in the physical and chemical condition of soil may alter the host parasite relationship. An improvement in soil condition due to soil amendment leads to more rapid root growth of plants. This enhances the utilization of soil nutrients and masks the effect of nematode damage.

Umarao and Goswami (1996) studied the comparative efficacy of soil amendments (groundnuts, karanj, mustard and neem) with carbofuran against *M. incognita* in cowpea. Reduction in root-knot development caused by *M. incognita* were significantly high in mustard, neem and carbofuran teatment, the least effective was the groundnut. Abid *et al.* (1995) found that soil amendment with neem cake, cotton cake and *Calotropis procera* each at 0.1, 0.5 and 1% (w/w) reduced infection of *M. incognita* on Mungbean. Mustard cake at

low dosages (0.1 and 0.5% w/w) effectively reduced the gall formation but was phytotoxic at 1%.

Akhtar (1998) reported that soil amendments with various products prepared from neem such as leaf powder, saw dust and oil seed cake resulted in a significant decrease of plant parasitic nematodes as compared to untreated plots. Oil cake was most effective, though all the neem products markedly suppressed plant parasitic nematodes. All treatments resulted in an increase fresh and dry weight, height and number of pods on chickpea plants.

In another field experiment Akhtar (1998) applied two neem based granular products, i.e. Achook and SuneemG (containing azadirachta), urea and compost manure at different doses. Combination of neem products with urea were the most effective in suppressing plant parasitic nematode populations. The growth of pigeonpea was improved in all the treatments. Agyarko *et al.* (2005) assessed nematode population at two week interval in soil amended with neem leaves and animal manure. It was found that the number of plant parasitic nematodes decreased significantly with the application of neem based amendments, whereas the number of non plant parasitic nematodes increased. Animal manure (poultry manure and cow dung) were also effective in controlling plant parasitic nematodes, however, neem based amendment gave higher efficacy than the animal manure treatments. Nazir *et al.* (2005) tested the comparative efficacy of crude neem products (leaves, cake and seeds) at 3% and refined neem seed extract (25, 50, 100 and 500 mg /100g of soil) against juveniles of *M. javanica*. It was observed that neem products significantly reduced the mobility of juveniles in the treated soil. Among the neem products, neem leaves were more toxic to juveniles compared with the neem cake and seeds. In an experiment the effectiveness of aqueos and ethanol neem extract was studied against second stage juveniles of *M. incognita*. Both aqeoous and ethanol extract were effective in causing mortality of

nematodes, however, ethanol extract of neem seeds was comparatively more toxic (Javed *et al.*, 2007).

## 2.22 Host resistance

Growing resistant cultivars can be an ideal way of maintaining nematode population densities below damaging levels. The use of resistance could be the most suited nematode management strategy as it has got advantages of preventing nematode reproduction; there is no need to go for long term rotation and crop can be grown on nematode infested land with resistance; it does neither produce toxic residue nor any special application technique or additional cost is required. Initial identification of resistant or tolerant sources in pigeonpea is essential to start breeding for economically important nematodes such as root-knot, cyst nematode and reniform nematodes. In screening assays, plant population has to be exposed to nematode in such a way that the resistant plants can be distinguished from the susceptible ones. In case of root-knot nematodes, severity of plant symptoms such as galling can be taken into consideration for evaluating plant reaction to nematodes. However only the galling does not indicate that the nematode can reproduce, but may merely be the resistant plant reaction to invasion. In some of the genotypes of pigeonpea, only egg masses are produced not the galls (Sharma *et al.*, 1994), so galling and reproduction can be considered for plant reaction to root-knot nematodes. Resistant plant acts as a barrier for nematodes in a number of ways such as it retards the rate of reproduction, delays the maturity of the parasite, production of more males and making nematodes unable to complete its development.

Several pigeonpea breeding lines have shown to be highly resistant to both *M. incognita* and *M. javanica*. The line with resistance to *Fusarium udum* were all susceptible to the nematodes (Patel *et. al.*, 1987). Out of 47 lines of pigeonpea, 36 were rated as

resistant against *M. incognita* based only on galling under field conditions (Ravichandra *et al.,* 1988). Patel *et al.* (1987) reported pigeonpea lines, 18-1 and 77-1 as highly resistant to mixed population of *M. incognita* and *M. javanica*. Rahman *et al.*,(2004) screened 102 genotypes of pigeonpea against *M. incognita*. Out of 102 genotypes, 14 were highly resistant and 57 were resistant to root-knot nematode *M. incognita*.

## 2.23 Plant Products

The effect of various plant products as seed treatment might be due to the direct nematode toxicity of the seed coatings causing unfavorable environment for nematode activity or possibly the plants grown from coated seeds acquiring resistance or tolerance to the nematode (Siddiqui and Alam, 1989; Wani, 1992). These might have influenced the metabolism of the germinating seeds rendering the seedlings unfavourable for nematode multiplication as well as stimulating plant growth (Siddiqui and Alam, 1988). Seed dressing of pigeonpea and chickpea with latex of *Calotropis procera* resulted in significant control of *M. incognita* and *R. reniformis* with a corresponding increase in plant growth, chlorophyll, water absorption capacity of roots and root nodulation (Mojumder and Mishra, 1991). Latif *et al.* (1999) also found a reduction in root penetration on cowpea by *M. incognita* juveniles when seeds were treated with *C. procera*. Saravanapriya *et al.* (2004) tested the efficacy of 15 plant products against *M. incognita* for egg hatch. The latex of *C. papaya* caused 98 and 100% hatching inhibition at 1 and 10% concentrations, respectively. The latex of *C. gigantea* also caused 100% inhibition at 10% concentration.

## 2.24 Neem products

Seed treatment of chickpea with neem seed kernel, neem seed coat and Achook at dosages (5-20% w/w) were found effective in reducing penetration and multiplication of second stage juveniles of *M. incognita* and nematode multiplication (Mojumder and Basu,

1999). In another experiment Mojumder and Raman (1999) reported that seed treatment with neem seed kernel, neem seed coat (seed shell) and neem seed cake @ 20% w/w reduced *M. incognita* and *R. reniformis* multiplication in mungbean and chickpea under greenhouse trials. These treatments under field condition also reduced the population of *M. incognita, R. reniformis, Tylenchorhynchus mashhoodi, Helicotylenchus indicus, Hoplolaimus indicus* in both the crops. In either case, neem seed kernel was the most effective followed by neem seed cake and neem seed coat (seed shell).

Mojumder (1999) studied the effect of seed treatment of chickpea seeds with 20% (w/w) powdered neem formulations *viz*, seed kernel, seed coat, de-oiled cake and Achook (a commercial neem product) and 5% (v/w) liquid formulations viz., Neemark and Nimbicidine on the nematode population growth and grain yield under field condition. At the time of harvest there was a significant reduction in the population of *M. incognita, R. reniformis, T. mashhoodi, Helicotylenchus indicus* and *Hoplolaimus indicus* in all the treatments while the saprophytic nematodes multiplied freely in both the trials. All the treatments increased the grain yield significantly.

In another experiment Mojumder and Mishra (1993) reported that seed soaking with aqeous extract of neem seed kernel and seed coat with neem seed powder reduce the number of root-knot galls in mungbean plants. The population of *M. incognita* juveniles also decreased in the soil. Significant effects were obtained with 100 and 50% concentration for 3 hours soaking or 50% and 25% concentrations for 6 hours soaking. Seed treatment of chickpea with different neem products and soil application of systemaic nematicides indicated that neem seed powder @10% (w/w) along with carbofuran @ 1kg a.i./ha was most effective management package against *M. incognita* (Chakrabarti and Mishra, 2001). The crude neem products viz., neem cake and neem seed powder were more effective than commercial neem based formulations.

Among various neem based materials such as neem seed powder, Achook, Neemark, Neemgold, Nimbecidine and Field Marshal, neem seed powder was found more effective in suppressing populations of *M. incognita, H. cajani* and *R. reniformis* infecting pigeonpea followed by Neemgold and Neemark. Achook and Field Marshal were less effective (Das and Mishra, 2000, 2002, 2003). Ali and Askary (2004) observed maximum reduction in root-knot galls of pigeonpea plants when seeds were treated with neem seed powder. However, number of bacterial nodules and number of pods per plant were highest when seeds were treated with Neemark, a neem based product. Anver (2003) found oil seed cakes of neem to be highly effective in reducing the multiplication of nematodes and consequently increasing the plant growth and bulk density of woody stem of pigeonpea. In an experiment the shade dried leaves, bark and kernel of neem were tested to study the effect of egg hatching of *M. incognita*. The result showed that increase in concentration of neem extract and exposure period caused an inhibitory effect on egg hatching of *M. incognita*. The most effective was neem kernel and the least was neem bark (Singh and Dabur, 2004).

## 2.25 Biological control

Biological control may be defined as the reduction in the population or disease/damage causing activity of a part or a pathogen in its active or dormant state by one or more organisms that occur naturally or through manipulation of the environment or by mass introduction of anatagonists (Stirling, 1991).

The bio-control programme aims to maintain the pest population below the economic thresholds level, rather than eliminating a pathogen as done by the chemicals. Hence, technically bio-control is reduction in pest population accomplished through the introduction of antagonists or manipulating the environment to make it congenial for the activity of naturally occurring antagonists. Control of root-knot nematodes has been

accomplished primarily through chemical nematicides, crop rotation and resistant cultivars where available (Widmer and Abawi, 2000). Because many nematicides have been banned for use in nematode management t for toxicological reasons or are scheduled for phasing out, research into nematode control alternatives has been greatly stimulated (Nico *et al.*, 2004).

Hartley (1921) was the first who used micro-organisms into soil to control root diseases by introducing 12 isolates of saprophytic fungi and one bacterium in nursery bed against damping-off of pine seedlings caused by *Pythium debaryanum.* Invention of some chemical pesticides and their commercialization in 1940s onwards, however, sidelined the biological control. The approach of biocontrol, however, got revived when failure of pesticides and their ill effects were realized.

In the past two decades there is an increasing evidence to determine the potential of opportunistic soil fungi to parasitize females and eggs of endoparasitic nematodes. Several predaceous fungi, bacteria, rickettsias and sporozoans are now known to reduce nematode population and parasitize nematode eggs, females and cyst. Some of these organisms have been found quite useful in nematode management. *Paecilomyces lilacinus, Pochonia chlamydosporia, Aspergillus niger, Dactylaria candida, Arthrobotrys robusta* etc. are important fungi which may parasitize nematodes and decrease their population.

## 2.26 *Paecilomyces lilacinus* (=*Penicillium lilacinum*) (Thom, 1910) (Thom) Samson, 1974.

### 2.26.1 Morphology

*P. lilacinus* shows fast hyphal growth, forms a dense mycelium which give rise to conidiophores. The conidiophores bear phialides from the ends of which spores are formed in long chains. Phialides are bottle shaped consisting of a swollen basal part, tapering into a

thin distinct neck. Conidia are lilac in colour, and in divergent chains, ellipsoid to fusiform, smooth walled to slightly roughened.

*P. lilacinus*, before infecting a nematode egg, flattens against the egg surface and becomes closely appressed to it. The fungus produces simple appressoria anywhere on the nematode egg shell wither after a few hyphae grow along the egg surface, or after a network of hyphae form on the egg. The presence of appressorium appears to indicate that the egg is, or is about to be infected. In either case, the appression appears the same, as a simple swelling at the end ofa hyphae, closely appressed to the egg shell. Adhesion between the appressorium and nematode egg surface must be strong enough to withstand the opposing force produced by the extending tip of a penetration hypha (Money, 1998). After penetrating the egg, hypha rapidly destroys the juvenile within it. Later on a large number of conidiophores are produced and hypha moves towards adjacent eggs. Bonants *et al.* (1995) identified a basic serine protease from *P. lilacinus* with biological activity against *Meloidogyne hapla* eggs. *P. lilacinus* has also been reported to produce proteases and chitinase. The enzymes break down the egg shell thereby making the way for fungus to pass through.

The association of *P. lilacinus* with nematode eggs was for the first time observed by Lysek (1966). Later on Jatala *et al.* (1979) reported the fungus parasiting eggs of *M. incognita* in Peru. The fungus has now been isolated from many cysts, root-knot nematodes and soil in many locations (Stirling, 1991; Stirling and West, 1991). *P. lilacinus* is sometimes also able to infect mobile nematode stages or sedentary females, but it is most aggressive against eggs (Cabanillas and Barker, 1989). Barker and Cook (1974) have found *P. lilacinus* infecting *R. reniformis* both in greenhouse and field conditions. The pigeonpea seeds when treated with *P. lilacinus*, the multiplication rate of *M. incognita* and *R. reniformis* decreased (Anver and Alam, 1997).

Kiewnick and Sikora (2006) evaluated *P. lilacinus* strain 251 under different temperature regimes for the control of *M. hapla*. A significant interaction between the nematode inoculum density and fungal treatment was observed at low temperature at which a few few root knot galls and egg masses were formed. When the temperature was favorable for the fungal parasite (25°C), efficacy reached 90%.

Various formulations of *P. lilacinus* have been developed and used to control plant parasitic nematodes. Commercial formulation of *P. lilacinus* (Phil. Strain No. 1) as BIOCON was developed by Asiatic Technologies Incorporation in Manilla (Davide, 1990). Another commercial product of *P. lilacinus* known as Yorker from Agriland Biotech has now been available in market and found effective against root-knot nematodes (Gaur, 2002). *P. lilacinus* strain 251 (PL251) is currently commercialized and registered for sale as BIOACT®WG for the control of nematode pests in several countries (Kiewnick, 2004; Atkins *et al.*, 2005). Moreover, PL251 has recently received United States EPA registration as a biological nematicide under the trade name Melocon®WG (EPA, 2005).

### 2.27 *Aspergillus niger* (Van Tieghem, 1867)

Hyphae are septate and hyaline. Conidial heads are radiate initially, splitting into columns at maturity. The species is biseriate (vesicles produces sterile cells known as metulae that support the conidiogenous phialides). Conidiophores are long, smooth and hyaline, becoming darker at the apex and terminating in a globose vesicle. Metulae and phialides cover the entire vesicle. Conidia are brown to black, very rough and globose.

*Aspergillus niger* is an egg parasite of nematodes. As soon as the fungus comes in contact with a cyst or an egg mass rapidly grows and colonizes those eggs where larval formation has not been completed. However, when larva is formed the egg becomes less vulnerable. It has been suggested that this differential vulnerability of egg is due to

chitinolytic activity of these fungi. Chitin is a major constituent of the egg shell, while the larval cuticle lacks it. In some cases there is enzymatic disruption of nematode structural elements such as egg shell and larval cuticle or physiological disturbance due to bio-synthesis of diffusible toxic metabolites (Jatala, 1985; Jatala, 1986).

Toxicity of culture filtrate of *A. niger* eggs and juveniles of *Meloidogyne* spp. It has been observed with 93.3% juvenile mortality when treated with 20 times diluted culture filtrate of the fungus (Dahiya and Singh, 1985).

Singh *et al.* (1991) have reported lesser damage to tomato due to *M. javanica* in the presence of *A. niger*. Zareen *et al.* (2001) tested the efficacy of filtrates of seven species of *Aspergillus* against *M. javanica* infesting tomato. *A. niger* was found most successful in minimizing root and soil densities of *M. javanica* in soil drench treatments compared to other species of *Aspergillus*. They found all isolates to be suppressive to nematodes but a few isolates *viz.*, $AnC_2$, $AnR_3$ and $AnM_1$ to be highly antagonistic to the nematodes.

In the recent years, some commercial formulations of *A. niger* have been prepared both for soil application as well as seed treatment. Kalisena SL, Pusa Mrida and Kalasipahi (capsules) are meant for soil application, whereas Kalisena SD and Beej Bandhu for seed dressing. Except Beej Bandhu all the formulations have an extraordinarily long shelf life of more than two years at 15-35°C when packed in polythene bags and stored under less than 80 percent relative humidity. Application of Kalisena SD increased the germination and seedling vigour of a number of crops (Sen, 2000). The formulations are effective in acidic and alkaline soils, under high and low moisture conditions at a soil temperature range of 18-45°C.

## 2.28 Integrated management of root-knot nematode

A variety of approaches based on physical, chemical, biological and cultural methods have been found effective to a varied extent, in reducing nematode population densities and improving crop performance. None of the methods except chemicals, have been found effective to completely control, or to maintain the population densities at levels below the economic tolerance level. In view of adverse effects of chemical and cost involvement, it is required to reduce their input. Hence, reliance has to be placed on a judicious combination of different practices suitable for location specific conditions.

The recent concept of nematode management has shifted to maintain nematode population densities below the economic injury threshold or to reduce with minimum inputs. This can be achieved through judicious integration of two or more different approaches of management. The integration of different strategies for nematode management, in fact, is not a new concept. Kuhn (1981) was probably the first to use fallowing with crop rotation for the control of nematodes. Tyler (1933) had already suggested that the combination of two or more control strategies into an overall management programme in the only sound and sustainable approach for the effective control of root-knot nematodes. Integrated nematode management (INM) seeks to stabilize population of target nematodes at acceptable levels resulting in long term socio-economic and environment friendly consequences. The aim of an ecologically sound integrated nematode management (INM) approach should be:

1. Utilization of several compatible measures.
2. Maximization of natural biotic and abiotic environmental resistance.
3. Understanding and counteracting nematode survival strategies.
4. Minimal use of drastic control measures.

5. Increased reliance on location specific and resource compatible management strategy.

6. Minimal input costs in harmony with potential gains.

7. Maximization of profit to the grower and

8. Minimization of environmental and health hazards.

Various INM systems have been suggested in both developed and developing countries. In India attempts have also been made to control nematodes by INM systems (Ravichandra and Krishnappa, 1985; Gaur and Prasad, 1986; Jayaraj *et al.*, 1993; Mahmood and Siddiqui, 1993; Gautum *et al.*, 1995; Wani, 2005). Integrated management strategies can be applied sequentially or simultaneously. The first approach includes the season to season or year to year integration of strategies and is particularly relevant to annual cropping cycles. The second major approach to INM involves simultaneous application of two or more strategies. This approach may be utilized for both annual and perennial crop production (Rhodes, 1984; Graffin, 1987; Alphey *et al.*, 1988). However, this approach requires extensive research because of the unique issues that require resolution such as compatibility and degree of efficacy.

Barker and Lucas (1984) have identified five components of a continous integrated programme for nematode management in tobacco, *viz.*, (i) destruction of roots and debris from previous crop; (ii) nematode free transplants; (iii) resistant cultivars; (iv) crop rotation and (v) availability of effective chemical treatments. In intensively cultivated vegetable crops, deep summer ploughing of the main field + nematicidal treatment / rabbing of nursery beds + incorporation of poor hosts / resistant variety in cropping sequences can be integrated to keep the nematode population below damaging threshold (Walia and Bajaj, 2001).

## 2.29 Fusarium wilt (*Fusarium udum* Butler)

Fusarium wilt is the most important disease of pigeonpea and was first described from Bihar State of India (Butler, 1906). The disease appears in young seedlings but the highest mortality occurs at flowering and podding stage. Rai and Upadhaya (1982) described *Gibberella indica*, the perfect state of *F. udum* and proposed a new disease cycle. Even though plants are infected at an early stage, they seem able to "keep fighting with the fungus till maturity. The yield loss depends on the stage at which the plants wilt; the loss may be upto 100% when wilting occurs at the prepod stage, about 67% when wilt occurs at maturity and 30% when it occurs at the pre harvest stage (Kannaiyan and Nene, 1981). The fungus can be isolated from apparently healthy looking 15 days old plants form a wilt sick plot (Nene *et al.*,1980). The pathogen produces cellulase, polygalacturonase and pectin methyl esterase and fusaric acid which are involved in pathogenisis (Singh and Hussain, 1970).

Taxonomic position of *Fusarium udum*

| | |
|---|---|
| Division | Amastigomycota |
| Sub-Division | Deuteromycotina |
| Class | Deuteromycetes |
| Sub-Class | Hyphomycetidae |
| Order | Moniliales |
| Family | Tuberculariaceae |
| Genus | *Fusarium* |
| Species | *udum* |

### 2.29.1 Distribution and economic importance

To date fusarium wilt has been reported from 15 countries *viz.*, Bangladesh, Ghana, Grenada, India, Indonesia, Kenya, Malawi, Mauritius, Nepal, Pakistan, Tanzania, Thailand, Trinidad, Uganda, venezuela (Nene *et al.*, 1989), but it is relatively more important in India and eastern Africa. In India the wilt occurs in almost every state in which pigeonpea is grown. The average incidence of the wilt in India varies from 0.1% in Rajasthan to 22.6% in Maharashtra (Kannaiyan *et al.*, 1984). The disease also occur in severe form in Bihar (10-20%) and Uttar Pradesh (5.1-10%), while comparatively moderate in other states (≤5.0%). Recently Chauhan and Kumar (2004) conducted a survey in 15 districts of eastern Uttar Pradesh to record the incidence of wilt diseae in pigeonpea and observed incidence of 14.7% in the Ghazipur district followed by 10-12% in Jaunpur, Varanasi, Gorakhpur and Azamgarh.

The annual pigeonpea crop loss due to wilt in India alone has been estimated at US $ 36 million, while in eastern Africa annual losses were estimated at US $ 5 million (Kannaiyan *et al.*, 1984). The production loss due to wilt in pigeonpea has been estimated to be 32 thousand tons in Uttar Pradesh, 44 thousand tons in Maharashtra and 10,000 tons in Madhya Pradesh state of India (Singh, 1994).

### 2.29.2 Symptoms

The infection by *F. udum* is systemic, occurring through fine lateral roots by the germ hyphae, produced by the conidia, chlamydospores or ascospores (Rai and Upadhayay, 1982). The pathogen enters the vascular system and traverses all along, producing conidia and chlamydospores within the xylem vessels. The xylem vessels are frequently blocked by clumps of mycelia of the pathogen. Blackening due to infection frequently appears in vascular tissue of the host. Symptoms can appear 4 to 6 weeks after sowing (Reddy *et al.*,

1990; Upadhayay and Rai, 1992). The initial visible symptoms are loss of turgidity in leaves, and slight interveinal clearing. The foliage shows slight chlorosis and sometimes becomes bright yellow before wilting. Leaves are retained on wilted plants.

The characteristic of internal symptoms of wilt at initial stage is the browning of the xylem vessels from the root system to the stems. The xylem gradually develops black streaks, and brown or dark purple bands appear on the stem surface of partially wilted plants extending upwards from the base. When the bark of such bands is peeled off, underneath browning or blackening of the wood can be seen. In wilt tolerant genotypes these bands are confined to the basal part of the plant. In the later stages of the plant growth, the branches dry from the top downwards and finally the death of the whole plant may occur. Lateral root infection results in partial wilting whereas tap-root infection causes complete wilting.

**2.29.3 The causal organism**

The fusarial wilt in pigeonpea is caused by *Fusarium udum* Butler. Rai and Upadhayay (1982) reported *Gibberella indica* as the perfect stage of *F. udum.* The pathogen is specific in parasitism, being pathogenic to pigeonpea only (Upadhayay and Rai, 1989; Kannaiyan *et al.,* 1985). It is a soil borne facultative parasite that enters through roots and then becomes systemic. It can be isolated from all parts of the host from lateral fine roots to pedicel and pod hull (Nene *et al.,* 1979). The pathogen extends more rapidly from one place to another along the root than across the soil. It is dispersed through irrigation, rain water and displacement of host debris by termites that feed frequently on dead wilted plants (Upadhayay and Rai, 1982). The fungus has also been found to be seed borne in nature (Upadhayay and Rai, 1992).

*Fusarium udum* shows a great deal of variation in cultural characteristics (Reddy and Chaudhary, 1985). The fungus inside the host is confined to vascular tissues and is both inter and intra-cellular. The mycelium is septate, hyaline and produces three types of spores

(microconidia, macroconidia and chlamydospores) within the host tissues as well as in cultures, depending on nutritional and other factors. Microconidia are small, elliptical or curved, unicellular or with 1-2 septa, and measures 5-15 x 2-4 m. They are formed free on hyphal branches. Macroconidia are produced in small cushions of stromatic mycelium on the surface of the host near ground level. The stromatic bases (sporodochia) are tubercular in culture media. The macroconidia are long, curved (fusaroid), pointed at the tip, and notched at the base, septate (3-4 septa), and measure 15-50 x 3-5 m. Chlamydospores are also formed in the host as well as in old cultures. They develop from any cell of the hypha, often from cells of the macroconidium. The cells round off and become thickwalled to form chlamydospores. These spores are oval or spherical, single or in chains, terminal or intercalary, and survive in the soil for longer periods. The perfect stage, *Gibberella indica* is usually found on exposed roots and collar region of the stem up to the height of 35 cm above the ground (Upadhayay and Rai, 1982). The mature perithecia are superficial, commonly aggregated, subglobose to golobose, sessile, smooth walled, dark violet and 350-550 μm in diameter. Asci are 8 spored, mostly subcylindrical, 60-80 x 6-10 μm, broader in the middle, with short stalk, a narrow apex, and a central apical pore. Ascospores are ellipsoidal to ovate, 10-17 x 5-7 μm, hyaline, commonly 2 celled, rarely 3-4 celled and constricted at the septa. In culture, these spores germinate to produce short or long conidiophores bearing micro and macroconidia which are pathogenic to pigeonpea. The fungus is heterothallic and single ascospore culture does not produce perithecia. When cultures from different strains are grown together perithecia are formed after 25 days at 18-22°C.

The pathogen has been reported to produce three enzymes viz., pectin methyl esterase, polygalacturonase, and cellulase *in vivo* and *in vitro* (Singh and Husain, 1962 and 1968; Upadhayay and Rai, 1989) and a toxin fusaric acid (Singh and Husain, 1964; 1970)

which have been shown to play a role in pathogenicity. The fungus is a mycoparasite of certain fungi such as *Rhizopus nigricans, Curvularia lunata, Rhizoctonia solani* etc. (Singh, 1998).

*Fusarium udum* can survive saprophytically in soil in the absence of its host for a period of 3-4 years. The fungus spreads from decaying roots into the soil and continues to grow forming the spores. The pathogen can survive in burried pigeonpea substrates for about 2-3 years (Nene *et al.*,1979; Nene and Reddy, 1981). It has been found that the crop sequence, use of fertilizers and other micronutrients, organic amendment with different substances (Singh, 1975), soil type and associated microflora (Upadhayay and Rai, 1982) influence the behaviour and survival of the pathogen in soil.

**2.29.4 Disease cycle**

The disease cycle was known earlier to occur only through the imperfect state. After discovery of the perfect state (Upadhay and Rai, 1983) the disease cycle of the wilt occurs both through imperfect stage (*F. udum*) and perfect stage (*G. indica*). However, the asexual cycle is more common since the perfect stage does not frequently develop in nature. In the either case the pathogen grows both externally and internally, producing a mass of mycelia and conidia on the surface of the host, particularly on the collar region and on the roots. The infection takes place through fine lateral branches of the roots and the fungus continues to grow in the xylem vessels. Consequently, upon wilting and host death the pathogen lives and survives saprophytically for several years, primarily on dead parts of the host in the imperfect (Nene *et al.*, 1980) or perfect state (Uphadhayay and Rai, 1983). The perfect state of pathogen occurs along with the imperfect state simultaneously on the host. The saprophytic survival is confined mostly in the infected dead roots and other host debris. However, the fungus may also survive for a limited period on organic matter other than the host. Mycoparasitic survival of *F. udum* on other fungi in soil has been reported recently

(Uphadhaya and Rai, 1983). *F. udum* propagules have been recorded from the bodies of termites which also feed on the wilted host roots (Upadhayay and Rai, 1982). Depending on the environmental conditions, chlamydospores are formed both in parasitic and saprophytic phases from the hyphae and conidial cells (Singh, 1975). These chlamydospores serve as structures of survival during prolonged absence of the host and at the advent of favourable conditions, the resting spores germinate to initiate infection. The spread of the disease occurs through contact, rain water and termites. After death of the infected plants the fungus lives saprophytically in the host substrates for a limited period and then forms chlamydospores to enter the dormant resting stage.

Sometimes a large number of dark violet perithecia are produced on the collar region and exposed roots of the host. These perithecia also serve as resting structures under unfavourable conditions. The perithecia of *F. udum* produce a large number of ascospores that remain in soil for a limited period under a physiologically inactive state, and under favourable conditions they produce somatic hyphae on germination either causing infection in the host roots or producing conidia which, in turn, may cause infection.

**2.29.5 Epidemiology**

The incidence and severity of the disease depend primarily on soil conditions and the host cultivar. The disease occurs commonly in the northern and central parts of India and being very severe along the bank of river Ganges. Slightly acidic to slightly alkaline soils containing 50% or more sand particles favour the disease incidence in susceptible cultivars (Singh and Hussain, 1964; Upadhayay, 1979). Soil temperature and moisture also play a significant role in the occurrence of wilt disease. Uphadhayay (1979) observed a 20-29°C temperature at 6-16% moisture to be most suitable for the disease development. Mundkur (1935), however, had earlier reported a temperature range of 12-29°C favourable for the disease. Upadhayay and Rai (1981) made an attempt to correlate the soil physico-

chemical properties with fungistates and the wilt of pigeonpea. They concluded that less incidence of the wilt disease in soils of southern states of India observed by Kannaiyan *et al.* (1984) might be due to a higher level of soil fungistates against the pathogen.

The disease incidence in a particular soil depends mainly on the saprophytic activity and survival of *F. udum* in soil which are favoured by continued presence of the host substrate. The disease becomes increasingly more severe when susceptible varieties of pigeonpea are grown in infested soils successively.

### 2.29.6 Management

In view of the prevalence of the wilt disease and the associated yield losses in pigeonpea, different efforts have been made towards the management of the disease. The management strategies can be accomplished by adopting both chemical and / or non-chemical methods.

### 2.29.7 Chemical Method

By the need based use of chemicals and undertaking the steps to safeguard the user and environment against any possible health hazard, chemicals provide the most reliable means of disease control (Vyas, 1993). A number of fungicides like thiram, captan, carbendazim etc. are available in market and control plant disease satisfactorily (Nene and Thapliyal, 1993). Soil application of thiram and benomyl effectively managed fusarial wilt (Singh, 1998). Soil drench of carbendazim or benomyl effectively decreased the wilt incidence on tomato and consequently increased the yield. Carbendazim was found significantly superior to benomyl. (Sen and Kapoor,1974). Sinha (1975) observed a satisfactory control of the disease by bavistin applied as soil drench at 2000 ppm, 10 days before inoculation of pigenpea with *F. udum.*

In laboratory experiments, bavistin was found highly effective in suppressing the mycelial growth. Haider *et al.* (1978) reported the disease control over three years by captan, brassicol (quintozene) and phenyl mercury acetate. Upadhyay and Rai (1981) found a considerable reduction in the wilt incidence of pigeonpea by phygon XL, dithane-78 and zincop. Spore germination of *F.udum* was completely inhibited by benlate and compogran-M at 50 ppm (Kotasthane *et al.*, 1987) and the mycelial growth was checked by bavistin and BAS 38601. The wilt incidence also decreased with the application of carbendazim as seed treatment resulting to a significant increase in the yield of pigeonpea (Agarwal *et al.*, 2003). Pandey and Upadhayay (1999) also recorded effective control of *F. udum* in pigeonpea due to carbendazim. However, the effect of the fungicide applied at the time of sowing did not persist for the whole copping season and thus necessitating another treatment of the fungicide. Synthetic formulations of anitiobiotics, griseofulvin (Chakrabarti and Nandi, 1969) abd bulbiformin (Vasudeva *et al.,* 1962) have been reported effective in controlling the disease. However, these antibiotics do not provide an economical appraoach to disease management (Upadhyay and Rai, 1992).

**2.29.8 Cultural method**

The plant diseases can be kept under control by adopting a good field sanitation. Removal of infected plants and their debris helps in keeping a low level of primary inoculum. Deep ploughing in summer and exposing the soil to sun is effective in reducing *Fusarium* wilt and root rot in chickpea and pigeonpea (Dhar, 2003). Crop rotation and mixed cropping are the traditional practices of disease management and the best way of eliminating soil borne infection (Upadhyay and Rai, 1982). Upadayay and Rai (1981) reported that mixed cropping of pigeonpea with *Crotalaria madicaginea* significantly suppressed fusarial wilt. Mixed cropping of pigeonpea with sorghum and seed treatment with vitavax significantly reduced the wilt incidence in pigeonpea (Mahalinga *et al.,* 2003).

Significant reduction in pigeonpea wilt (25-55%) has been obtained through crop rotation and intercropping/mixed cropping with sorghum (Dhar, 2003). Soil solarization by covering the soil with transparent polythene sheet continuously for 2-4 weeks during April to May in subtropics and tropics effectively controls fusarial wilt/root rot and also improved plant growth and yield (Dhar, 2003; Dhar and Chaudary, 2003).

### 2.29.9 Soil amendment

Soil amendments with *Azadirachta indica* or *ricinus communis* oil cakes, rice husk or saw dust favour the lytic effect of *B. subtilis* in soil against *F. udum* which affect the population of pathogen in soil (Singh and Singh, 1980). Organic amendment of soil with oil seed cakes of mahua (*Madhuca indica*), niger (*Guizotica abyssinica*), pongmia (*Pogmia glabra*) and tea (*camellia sinensis*) waste (2%) were found effective against *F. udum.* Application of pongmia decreased the fungal propagule count by 2.5 to 25.3 x $10^4$ cfu/g in 35 days (Somasekara *et al.,* 2000). Neem seed powder and neem cake has also been reported to inhibit the growth of *F. udum* (Srivastava and Mall, 2008).

### 2.29.10Host Resistance

Use of disease resistant varieties is the safest and easiest method to grow disease free crop. The search for sources of resistance to wilt in pigeonpea began way back in 1908 at Pune, India (Butler, 1908). Since then, abundant resistant germplasm of pigeonpea has been identified, but unfortunately only a few resistant cultivars are commercially available to farmers. The main reason for this seems to be lack of adequate efforts to breed high yielding varieties resistant to the fungus. There is a need to develop high yielding cultivars with wilt resistance in the short, medium and long duration group.

Multilocational testing in India (Nene *et al.,* 1989) and eastern Africa have helped to identify several lines resistant to wilt at different locations. Some lines ICP4769, 7118,

71825, 8863, 9168, 10958, 11299 showed broad based resistance. The lines that showed stable resistance in Kenya were ICP8864, 9145 and 10960 and in Malawi, the resistant lines were ICP7855, 9145, 9154, 9174, 9177, 10958, 11297, 11299 and 12738. Recently Gwata *et al.* (2006) screened a pigeonpea genotype ICEAP00068 in three different countries viz., Kenya, Malawi and Tanzania and found the genotype to be highly resistant to the wilt disease.

In the past few years, attention has been paid by researchers in India to identify the wilt resistant germplasm of pigeonpea. Barhate *et al.* (2000) have reported six pigeonpea cultivars, ICP-9174, ICP14280, ICP14514, ICPL88069, PI397430 and KPBR 80-22 resistant to *F. udum*. Mishra *et al.* (2003) evaluated 216 late maturing pigeonpea cultivars for multiple disease resistance; KAWR-2, 7, 16, 45 and 73 were found resistant to *F. udum*. The wilt resistance has also been identified at Rahuri in Maharashtra, where Mandhare *et al.* (2004) observed PT25-2, PI25, BSMR 841, BSMR23, IPA40 and KPL43 resistant to the fungus. Under field conditions in a wilt sick plot 88 genotypes of pigeonpea were evaluated for resistance against *F. udum*. In the fourth year of screening nine genotypes viz., Ra6, ICPL96047, 87119, 99055, 99046, 99048, 8863, 96048 and IPA04 were found resistant to disease (Mahesh *et al.* 2006).

### 2.30 Biological control

Prasad *et al.* (2002) reported the efficacy of *Trichoderma harzianum* both as seed treatment and soil application for the management of pigeonpea wilt caused by *F. udum* under field condition. However, soil application was found to be more effective than seed treatment in suppressing the disease. Seed treatment and soil application for the management of fusarial wilt disease in pigeonpea has also be confirmed by other workers (Jayalakshmi *et al.*, 2003; Sawant *et al.*, 2003; Mandhare and Suryawanshi, 2004;

Mahalinga *et al.*, 2004). Chaudhary and Prajapati (2004) evaluated six biocontrol agents *viz.*, *T. harzinum, T. viride* (Coimbatore); *T. viride* (Kanpur), *Aspergillus niger, Pencillium citrinurn* and (*T. gloicladium*) *virens* against *F. udum* causing pigeonpea wilt. The culture filtrates of all the bioagents used inhibited *F. udum* colony growth by 18.1-53.6% at different concentrations, highest being in *A. niger* which exhibited 36.4% mean growth inhibition. All biocontrol agents reduced pigeonpea wilt and *F. udum* population in the soil to a varied extent upto 90 days after sowing. Isolates of *T. harzianum* and *T. virens* when applied for the management of wilt disease in pigeonpea resulted to a significant reduction in disease as compared to untreated check (Roy and Sitansu, 2005). Khan (2005) have developed commercial formulation of *T. harzianum* and *Pseudomonas fluorescens* to control wilt of pigeonpea. Seed application of the formulations @ 2g / kg seed resulted to 4.8q / hac greater yield in pigeonpea. Combined application of carbendazim, *T. viride* and rhizobium as seed treatment resulted in a significant decrease in wilt incidence of pigeonpea caused by *F. udum* as compared to control (Raju *et al.*, 2005).

## 2.31 Integrated disease management

A reduction in *Fusarium* wilt disease and increase in the grain yield of pigeonpea has been reported when a combination of *T. viride* + *P. flourescens* + *Bacillus subtilis* + neem cake was used (Madhukeshwara and Seshadri, 2001). Integrated management of pigeonpea wilt by biotic agents viz., *T. harzianum, T. virens, Chaetomium globosum* and *B. subtilis* and a neem product, Amritguard has been reported by Singh *et al.* (2002). Application of zinc sulphate, farm yard manure and green manure in the soil and seed dressing with carbendazim and thiram (1:1 ratio) as well as *Trichoderma* spp. (4g/kg seed) in pigeonpea with sorghum as an intercrop under wilt sick soil condition resulted in a significant decrease in wilting and increase in crop yield than the application of each treatment alone (Bharathi *et al.*, 2006).

## 2.32 Nematode-wilt fungus interactions.

Fawcett (1931) recognized that nature does not work with pure culture and that many plant diseases are influenced by associated organisms. A single organism rarely infects a plant, although a few may reach economic injury level. The nature of economic injury, including the nature of biological association of the host with each pest as well as their mutual influences, is largely unknown. Under natural condition a plant is a potential host to various micro-organisms and they can influence each other by occupying the same ecological niche. Infection by one pathogen can alter the host response to subsequent infection by other pathogen (khan, 1993). Different parasites on the same plant interact, which result in disease complexes and these interactions may lead to susceptibility of the predisposition of the host plant by the nematode (Siddhu and Webster, 1981; Dasgupta, 1992; Khan, 1993).

Nematodes by themselves are capable of causing severe plant losses, however, when soil is infected with other pathogenic organisms in addition to pathogenic nematodes, the damage increases greatly. Among various interactions, the wilt disease complex caused by the wilt inducing fungi and root-knot nematodes are considered to be the most important in terms of their effects on the crop productivity. The combination of nematode and fungus often results in a synergistic interaction wherein the crop loss is greater than expected from either pathogen alone or an additive effective of the two together (Francl and Wheeler, 1993).

Atkinson (1892) for the first time reported that the infection caused by root-knot nematode, considerably increased the incidence and severity of *Fusarium* wilt in cotton. Since then, several cases involving *Meloidogyne* and *Fusarium* in disease complexes have been described on different hosts (Garber *et al.,* 1979; Sidhu and Webster, 1983; Hillocks

ıd Marley, 1996). In such interactions the nematode infection increases the severity of the ilt, breakdowns resistance to *Fusarium* and predispose plants to the fungus for greater athogenic damage. In a survey conducted in pigeonpea growing areas in U.P., India, the ilt disease complex caused by *F. udum, M. incognita* and *H. cajani* was identified to be ıe most severe problem in pigeonpea cultivation (Shukla and Haseeb, 2002).

Concomitant inoculation of the nematodes (*M. incognita* + *M. hapla*) and fungus (*F. xysporum, f.* sp. *pisi*) on pea cv. Little Marvel, at planting caused the death of the plants fter 45 days. The inoculation of *Meloidogyne* spp. at planting caused a severe stunting of ıe plants whereas *F. oxysporum* alone, at planting or 3 weeks later, caused no detrimental ffects (Padilla *et al.*, 1980). Ribeiro and Ferraz (1983) studied the interaction between *M. ıvanica* and *F. oxysporum f.* sp. *phaseoli* on bean (*Phaseolus vulgaris*). They found that ısceptibility of cultivars to the fungus was greater when both the organisms were present. ›rowth of chickpea reduced when both *M. javanica* and *F. oxysporum ciceri* were present ›gether irrespective of whether they were inoculated, simultaneously or with one week ıterval (Goel and Gupta, 1986).

In an another experiment Upadhyay and Dwivedi (1987) found that root-knot ematode *M. javanica* breaks wilt resistance in chickpea variety, Avrodhi. Plants inoculated vith *F. oxysporum* f. sp. *ciceri* alone showed slight wilting but wilting was maximum and apid in plants where nematode inoculation peceeded the fungus. They came to the onclusion that due to change in physiology of the host, wilt fungus was able to break host esistance.

Kumar *et al.* (1988) studied the effect of *M. incognita* and *F. oxysporum* f. sp. *ciceri* ın chickpea cv. JG-62 under pot condition. Simultaneous inoculation of both the pathogens esulted in greater reduction in the plant growth compared to other sequence of inoculation.

Salam and Khan (1986) studied the reaction of some cultivars of pigeonpea against *F. udum* and *M. javanica*. The result showed that the susceptiblity of all cultivars to *F. udum* increased when nematode and fungus were present together. Highly susceptible cultivars wilted sooner in the presence of both the pathogens than when inoculated with *F. udum* alone.

In a pot experiment Sharma and Nene (1990) tested the pathogenicity of *F. udum* in presence of *R. reniformis* and *Meloidogyne* spp. The result showed that the presence of the nematodes accelerated *Fusarium* wilt in wilt susceptible pigeonpea genotype, IC2376. The wilt resistant ICP8863 and tolerant genotype BDN1, however, were not affected by the presence of *R. reniformis*. Dwivedi *et al.* (1992) studied the interaction between *M. incognita* and *F. udum* on pigeonpea var. T21 in pot conditions. Suppression in plant growth and bacterial nodulation was more where plants were inoculated with fungus and nematode simultaneously.

Hillocks and Songa (1993) conducted a survey in eastern Kenya and observed that root-knot nematodes enhanced the infection of *F. udum* in pigeonpea plants. The association was found at only three sites out of 13 where *Fusarium* wilt occurred. Hillocks and Marley (1996) studied the combined effect of root-knot nematodes and *F. udum* on two wilt resistant cultivars of pigeonpea viz. ICP9145 and ICP8863. A susceptible reaction to *Fusarium* wilt was seen in case of ICP9145 whereas cv. ICP8863 remained unaffected. It was concluded that either the physiology of the response to nematode is different or that the mechanism of resistance to *Fusarium* wilt is different in the two cultivars.

The combined inoculation of *H. cajani, M. javanica* and *F. udum* at the higher inoculum doses of 1000 nematodes and 1 g fungus per pot caused the greatest damage to pigeonpea cv. UPAS 120. *H. cajani* and *F. udum* when inoculated together were more

pathogenic than the combination of *M. incognita* and *F. udum* (Siddiqui and Mahmood, 1996). In another study they observed that *H. cajani* and *F. udum* together caused more damage to pigeonpea than when both nematodes were inoculated together. Inoculation of nematodes prior to fungus increased the disease severity. *F. udum* and *B. japonicum* had an adverse effect on nematode multiplication (Siddiqui and Mahmood, 1999).

Mishra *et al.* (2003) evaluated the reaction of some *Fusarium* wilt resistant cultivars of pigeonpea to *H. cajani*. The wilt incidence was 20% under nematode inoculation but under combined inoculation of the two pathogens resulted 40% wilting. Inoculation with *F. udum* and *M. javanica* resulted to 8-50% greater wilting in five accessions of pigeonpea (Singh *et al.*, 2004). The plant height, fresh shoot and root weight and dry shoot and root weight were significantly lower in combined inoculation of nematode and fungus compared to either of the pathogen alone. Askary *et al.* (2005) evaluated five *Fusarium* wilt resistant accessions of pigeonpea against *F. udum* and *M javanica.* The wilting percentage in seedlings was observed 33-67% when both the organisms were present together. In pot and field studies, Khan (2005) has reported synergestic interaction between *M. incognita* and *F. udum* on pigeonpea leading to 12-18% greater reduction in plant growth and yield parameters compared to the sum of individual effects of the two pathogens.

### 2.33 Management of fungus-nematode wilt disease complex

The management strategies for disease complexes are necessary to modify and orient against all pathogens engaged in the disease complexes. In case of interaction disease the control of nematode component is of fundamental importance because fate of the disease complex is frequently governed by nematodes. Different methods of management of nematode fusarial wilt disease complexes have been adopted by researchers from time to time with varied degree of success.

### 2.33.1 Chemical method

Seed treatment with carbofuran (2%) + carbendazim (0.2%) effectively controlled the wilt complex of chickpea caused by *M. incognita* and *F. oxysporum* f. sp. *Ciceri* under field condition and improved seedling emergence and crop yield (Dwivedi and Upadhayay, 1988). Hasan (1989) demonstrated that aldicarb, carbofuran and phorate significanbtly reduced the severity of the disease complex involving *Heterodera cajani* and *F. udum* in pigeonpea. Dwivedi *et al.* (1992) reported that seed dressing with benlate (0.25%) was effective in maximum seed emergence of pigeonpea infested with *M. incognita* and *F. udum.*

Shahzad abd Ghaffar (1996) reported that carfofuran significantly reduced root-knot index and soil drenching with benomyl and mancozebe significantly reduced root colonization index of *F. oxysporum* on mungbean. A combined inolculation of both carbofuran and benomyl or mancozeb showed significant reduction in root-knot index of *M. incognita* and root colonization index *F. oxysporum.* The combined effect of carbendazim + carbofuran has also been found effective in controlling the nematode fusarium wilt disease complex in *Vigna mungo* (Haseeb *et al.*, 2005).

### 2.33.2 Cultural method

Incidence of the nematode-fungus disease complex can be maintained at low level by adopting a good field sanitation. Removal of infected plants and their debris helps in keeping a low level of primary inoculum. Deep ploughing in summer and exposing the soil to sun is effective in reducing *Fusarium* wilt and root rot in chickpea and pigeonpea (Dhar, 2003). Crop rotation and mixed cropping are the traditional practices of disease management and the best way of eliminating soil borne infection (Upadhayay and Rai, 1982). Upadhayay and Rai (1981) reported that mixed cropping of pigeonpea with

*Crotolaria madicaginea* significantly suppressed fusarial wilt. Mixed cropping of pigeonpea with sorghum and seed treatment with vitavax significantly reduced the wilt incidence in pigeonpea (Mahalinga *et al.*, 2003). Significant reduction in pigeonpea wilt (25-55%) has been obtained through crop rotation and intercropping/mixed cropping with sorghum (Dhar, 2003). Soil solarization by covering the soil with transparent polythene sheet continuously for 2-4 weeks during April-May in subtropics and tropics effectively controlled *Fusarium* wilt / root-rot disease and also improved plant growth and yield (Dhar, 2003, Dhar and Chaudhary, 2003).

### 2.33.3 Soil amendments

Soil amendments with oil cakes, rice husk or saw dust stimulated the lytic effect of *B. subtilis* in soil against *F. udum* resulting to significant decrease in the population of pathogen (Singh and Singh, 1980). Rai and Singh (1996) studied the efficacy of different amendments *viz.*, neem, mustard, mahua, coconut, linseed and sesame at different concentrations on *H. cajani, F. udum* and associated wilt of pigeonpea. Neem oil cake was found most effective in controlling wilt incidence caused by *F. udum* alone.Organic amendment of soil with the seed cakes of mahua (*Madhuca indica*), niger (*Guizotia abyssinica*), pongomia (*Pongmia glabra*) and tea (*Camellia sinensis*) waste (2%) were found effective against *F. udum*. Pongomia was not effective, but its application decreased the fungal propagule count by 2.5 to 25.3 x $10^4$ CFU/g in 35 days (Somasekara *et al.*, 2000).

## 2.34 Integrated disease management

Some efforts have been made to integrate two or more agents to control to develop a combined treatment for the management of wilt disease complex (Khan and Khan, 1999). A combined application of *Glomus mosseae, Paecilomyces lilacinus* and *Pseudomonas fluorescens* effectively controlled wilt of pigeonpea caused by *H. cajani* and *F. udum*.

Simultaneous use of biocontrol agents *P.lilacinus* and *Pochonia chlamydosporium* and *Gigaspora margarita* reduced the multiplication of the cyst nematode and wilt fungus on pigeonpea (Siddiqui and Mahmood, 1995). A combined inoculation of *Glomus fasciculatum, Trichoderma viride, P. lilacinus* and neem cake controlled the wilt disease complex of chickpea cv. H-108 caused by *M. incognita* and *F. oxysporum* f. spp. *ciceri.* The treatment reduced number of galls, egg mass and wilt incidence (Pandey *et al.,* 2005). Likewise application of commercial formulations of P. chlamydosporia and Pseudomonas fluorescens @ 2g /kg seed decreased the severity of wilt and root-knot and enhanced the yield of pigeonpea by 7.5 q / ha in a field study (Khan, 2005). Bharati *et al.* (2006) also in a field experiment on pigeonpea have shown that a combination of *Glomus fasciculatum* + *T. viride* + *P. lilacinus* + neem oil seed cake resulted to lowest number of root galls per plant, egg mass per plant, nematode soil population and wilt percentage.

# Chapter-3

# MATERIALS AND METHODS

## 3.1 Isolation, identification and mass culture of root-knot nematode, *Meloidogyne incognita.*

Infected root samples of egg plant showing galls or knots were collected from cultivation units. The samples were brought to lab and association of *Meloidogyne incognita* was confirmed using perineal pattern technique (Barker *et al.,* 1985). Pure culture of *M. incognita* was prepared by singly egg mass inoculation technique (Khan and Khan, 1991). A female along with the attached egg mass was excised from a gall. The species, *M. incognita* was identified on perineal pattern characters. Thereafter, the egg mass was placed near the roots of a seedling of egg plant, *Solanum melongena* L. cv. PPL grown in sterilized soil in a clay pot. The nematode culture from this plant was raised in sterilized soil on egg plant in numerous pots. For field inoculation, the nematode culture was prepared from the egg masses excised from the egg plants grown in pots. The egg masses were placed on wire gauze in a Bearmann funnel and incubated at 25-30°C for 6-10 days. The hatched juveniles were collected from the funnel.

## 3.2 Isolation and identification of the wilt fungus

Pigeonpea plants showing characteristic wilt symptoms were collected from farmer's field in Aligarh. The infected root and stem samples were washed in running tap water. The samples were cut into small pieces and immersed with 0.1% mercuric chloride ($HgCl_2$) solution for one minute and then gently washed 2-3 times in double distilled water. The pieces were transferred aseptically to a petri plate containing solidified potato dextrose agar (PDA) under a laminar flow hood. The inoculated plates were incubated in an incubator at 25±2°C for 5 to 6 days. The fungal colonies developed in the plates were subcultured on PDA slants.

Pigeonpea wilt pathogen, *Fusarium udum* was identified on the basis of its cultural and morphological characters (Upadhayay and Rai, 1992). Temporary slides of the fungus were prepared in cotton blue and examined under compound microscope. The fungus was

also compared with standard culture procured from the I.A.R.I., New Delhi and IMTECH, Chandigarh. The isolate was also identified from the National Bureau of Agriculturally Important Micro-organisms (NBAIM), MAU and Regional Research Laboratory, CSIR, Jammu, India where it has been deposited.

### 3.3 Mass culture of the wilt fungus and pathogenicity test

The mass culture of *F. udum* was prepared on sorghum seeds. The seeds were soaked overnight in 5% sucrose and 0.0003% chloramphenicol solution (Whitehead, 1957). The seeds were transferred to conical flasks of 500 ml capacity. The flasks were autoclaved twice at 15 $Kg/m^2$ pressure at 121°C for 15-20 minutes. Thereafter, the flasks were inoculated with the pure culture of *F. udum* and incubated for 8-10 days in an incubator at 27±2°C. During inoculation, the flasks were shaken daily manually for a few minutes for uniform colonization of seeds. The inoculum so prepared was incorporated in the pots containing sterilized soil (2g/kg soil) and mixed thoroughly. Five replicates were maintained and in each pot surface sterilized 5 seeds of pigeonpea were sown. The pots were irrigated with tap water regularly to maintain adequate moisture. Symptoms developed were observed 30 days after sowing. The pathogen was reisolated from roots and/or stem of infected plants and Koch's postules were proved. The pathogenicity test was repeated to confirm the results. The fungus was purified and compared with the previously isolated fungus.

### 3.4 Surface sterilization and bacterization of seeds

The pigeonpea seeds were first emerged in 0.01% $NaHCl_2$ solution for 5 minutes. Thereafter the seeds were rinsed with distilled water several times to remove residue of $NaHCl_2$. After surface sterilization the seeds were sprinkled with gum _rabica followed by the application of commercial rhizobium of pigeonpea strain (IARI, New Delhi). The seeds were thoroughly mixed to obtain homogeneous distribution of the rhizobium. The seeds were left in shed for 3 to 5 hours, thereafter used (sown) in all experiments conducted under pot or field condition.

## 3.5 Pot experiment

### 3.5.1 Effect of *F. udum and M. incognita* alone and in combination on pigeonpea.

In order to determine the influence of *F. udum* and *M. incognita* alone and in combination on pigeonpea seedlings pot experiments were conducted. Seeds of twenty five cultivars/accession of pigeonpea were obtained from Indian Institute of Pulses Research (IIPR), Kanpur. A total of 1125 clay pots (15 cm diameter and height) were filled with steam sterilized soil amended with compost (3:1). Twenty five pigeonpea cultivars/accessions used in the experiment were Manak, ICPL 87, ICP 14722, AL201, C-11, Sarvodaya, ICP 8859, ICPL 89049, DPPA 85-13, ICPL 89048, ICPL 87119, AKT 811, CO-6, GAUT 001E, GT 100, Pusa 84, AWR 74/15, ICP 8863, AL 15, Pusa 855, Bahar, GCP 33, Pusa 33, Paras and UPAS 120. One plant was maintained in each pot. The treatments for each accession were as follows:

1. Plant (Control)
2. Plant + *Fusarium udum* (1 g/kg soil).
3. Plant + *F. udum* (2 g/kg soil)
4. Plant + *F. udum* (4 g/kg soil).
5. Plant + *M. incognita* (500 $J_2$/kg soil)
6. Plant + *M. incognita* (1000 $J_2$/kg soil)
7. Plant + *M. incognita* (2000 $J_2$/kg soil)
8. Plant + *F. udum* (1 g/kg soil) + *M. incognita* (500 $J_2$/kg soil)
9. Plant + *F. udum* (2 g/kg soil ) +*M. incognita* (500 $J_2$/kg soil)
10. Plant + *F. udum* (4 g/kg soil) + *M. incognita* (500 $J_2$/kg soil)
11. Plant + *F. udum* (1 g/kg soil )+ *M. incognita* (1000 $J_2$/kg soil)
12. Plant + *F. udum* (2 g/kg soil )+*M. incognita* (1000 $J_2$/kg soil)
13. Plant + *F. udum* (4 g/kg soil)+*M. incognita* (1000 $J_2$/kg soil)
14. Plant + *F .udum* (1 g/kg soil)+*M. incognita* (2000 $J_2$/kg soil)
15. Plant + *F. udum* (2 g/kg soil)+*M. incognita* (2000 $J_2$/kg soil)
16. Plant + *F.udum* (4 g/kg soil)+*M. incognita* (2000 $J_2$/kg soil)

*F. udum* was applied @ 2 x $10^8$ CFUs/g SS, two days before the sowing of the seeds. Application of second stage juveniles of *M. incognita* in pot soil was done as per the method described in the previous pot experiment.

### 3.5.2 Integrated Management of root-knot nematode, *Meloidogyne incognita* and wilt fungus *Fusarium udum* through seed treatment under pot culture condition.

Efficacy of different chemicals, botanical and neem seed powder alone and in combination were tested as seed treatment under pot culture condition for the management of root-knot wilt disease complex in pigeonpea, cv. UPAS 120. Certified seeds of pigeonpea, *Cajanus cajan* (L) Millsp. cv. UPAS 120 were procured from an authorized dealer. The UPAS 120 is a short duration cultivar and matures in 120 days. The mycoflora examination of seeds (external and internal) through blotter paper test (Tempe, 1970) revealed absence of *F. udum* or other potential pathogenic fungi on the seeds of pigeonpea cv. UPAS 120 used in the study. The seeds were sown in clay pots (15 cm diameter and height) filled with steam sterilized soil amended with compost (3:1). Combinations followed for the experiment were as follows:

1. Plant (Control)
2. Plant + Dimethoate 30EC @ 0.8%
3. Plant + Latex of *Calotropis procera* @ 1%
4. Plant + Neem seed powder @ 5%.
5. Plant + Dimethode (0.8%) + Latex of *C. procera* (1%)
6. Plant + Latex of *C. procera* (1%) + Neem seed powder (5%)
7. Plant + Dimethoate (0.8%) + Neem seed powder (5%)
8. Plant + Dimethoate (0.8%) + Neem seed powder (5%) + Latex of *C. procera* (1%)

Each of the combination mentioned above was applied with the following treatments.

a. *Meloidogyne incognita* (2000 $J_2$ /kg soil).
b. *Fusarium udum* (2 g/kg soil).
c. *M. incognita* (2000 $J_2$/ kg soil) + *F. udum* (2 g/kg soil).

*F. udum* and freshly hatched second stage juveniles of *M. incognita* were applied one day before the sowing of seeds. Six replicates were maintained for each treatment. Plants were grown for four months. During this period they were regularly observed for any symptom.

## 3.6 Field Experiment

### 3.6.1 Effect of root-knot nematode *M. incognita* and wilt fungus *F. udum* on pigeonpea

The experiment was conducted to determine the efficacy of combination of *M. incognita* and *F. udum* singly or concomitantly, based on the performance in the previous experiments against the wilt, root knot and wilt disease complex of pigeonpea under field condition. The soil was sandy clay loam (66.7% sand, 19% silt, clay 14.3%), water holding capacity 43%, pH 7.9, organic carbon 0.016, percent organic carbon 1.9 and available phosphorus 15.2 kg/ha. A field of 70 x 40m in the Institute Farm, Aligarh Muslim University was prepared by adding 4 tons farm yard manure during ploughing. In the prepared field 300 microplots (2 x 4 m) were prepared with 0.5 m wide and 0.25 m high bunding (margins) to permit flood irrigation to individual plots. The width of the bunding was considered adequate to minimize possible lateral movement of nematodes or microorganisms. The pigeonpea cultivars/accessions were the same as used for the pot experiment. The following treatments were maintained for each cultivars/ accession of pigeonpea as soil application.

1. Plant (Control).
2. Plant + *F. udum*
3. Plant + *M. incognita*
4. Plant + *F. udum* + *M. incognita.*

For each treatment, three microplots (replicates) were randomly arranged in the field.

## 3.7 Application of Pathogens

### *3.7.1 Fusarium udum*

Sorghum seeds colonized by *F. udum* were grinded with known volume of distilled water in an electric grinder. Ten ml suspension containing 2 g fungus colonized seeds (2 x $10^8$ CFUs/g SS) was applied @ 2 g/kg soil in top layer. Weight of the top soil to 10 cm depth in a microplot of 2 x 4 m was estimated as 355 kg. Hence, the fungus suspension containing 710 g colonised seeds grinded in 10 litre tap water was sprinkled in a microplot to achieve uniform distribution of the pathogen. The inoculation was done two days prior to seed sowing.

### 3.7.2 *Meloidogyne incognita*

Nematode inoculation was done @ 2000 second stage juveniles/kg soil. Ten litres water containing 7,10,000 second stage juveniles of *M. incognita* was added to a microplot to obtain uniform population of the nematode. The inoculation was done a day before the seed sowing.

### 3.7.3 *Fusarium udum*

Soil population of the wilt fungus (*F. udum*) was estimated monthly using dilution plate method (Wakskman, 1927). Soil was collected from the rhizosphere of the plants from pots and from each microplot and was mixed to make a composite sample. The soil was sieved through a course sieve. One gram of the soil was taken in a conical flask to which 9 ml sterile water was added. The soil water mixture was stirred over a magnetic stirrer for 5 minutes. One ml of this suspension was transferred to 9 ml sterile water in a test tube. One ml sample was then transferred to another tube containing 9 ml sterile water. The process was repeated till the desired dilution of 1: 100000 were achieved. Each suspension was shaken over magnetic stirrer for few seconds and was in motion while being drawn into the micropipette. From the final dilution 0.1 ml suspension was aseptically spread (under Laminar flow) over solidified *Fusarium* specific medium. Three plates were maintained for each dilution. The agar plates were prepared four days previously to ensure that the medium in the plate was free from contamination. The plates were then incubated at 27 ± 2°C for 5-10 days to get the colonies. After incubation the plates were examined under a colony counter to determine soil population of the microorganism on the basis of morphological and PCR-RADP tests.

### 3.7.4 Generation of RADP profiles (Hardys *et al.*, 1992; Tingey and del Tufo, 1993)

To confirm identity of the wilt fungus *Fusarium udum* recovered from field plots after application in soil and to distinguish them from the native populations of morphologically similar bacteria or fungi, Rapid Amplified Polymorphic DNA (RAPD) profiles were prepared. The PCR-RAPD analysis was conducted at the Regional Research Laboratory, CSIR, Jammu, India.

### 3.7.5 Genomic DNA isolation from fungi by Cetyl trimethyl ammonium bromide (CTAB) method

The CTAB extraction buffer was prepared with 1% (w/v) CTAB, 50 mM Tris. Cl (pH 8.0), 10 mM EDTA (pH 8.0) and 0.7 M Sodium chloride. The 5 µl of b--mercaptoethanol was added to 500 µl extraction buffer just before use. The fungi, *Fusarium udum*, was grown in 100 ml of Sabouraud Dextrose Agar at 28°C with constant shaking for 3 days and the mycelia were harvested by filtration. The mycelia were freeze-dried for 5-6 hours. Thereafter, 6 ml (CTAB) extraction buffer and 60 µl of b--mercaptoethanol were added to the mycelia and the contents were mixed thoroughly. After incubation at 65°C for 45 min, the contents were allowed to cool. This was followed by an extraction with equal volume of chloroform at 10,000 x g for 10 min. The supernatant was added to a sterile centrifuge tube and an equal volume of isopropanol was added and mixed gently. The DNA was spooled out with a fine capillary or pelleted by centrifugation. The isopropanol was drained and the DNA pellet was washed with 70% (v/v) ethanol. The DNA pellet was vacuum dried and dissolved in 100 µl of Tris-EDTA buffer (TE) (pH 8.0) or Millipore-sterilized water.

### 3.7.6 Polymerase Chain Reaction (PCR) assays

Polymerase chain reactions were performed using crude cell lysates of extracted DNA of *F. udum*. All the reaction components were thawed in an ice bath and spinned briefly prior to the assay. The reactions were set up in a bio-hood using sterile filter-guard microtips and thin-walled PCR tubes. A 20 µl reaction assay mixture was prepared containing 1 x PCR buffer, 200 µM each dNTP, 1.5 mM $MgCl_2$, 20 pmol of the primer, 5 ng of DNA and 1 U of Taq DNA polymerase. The PCRs were performed in Mastercycler gradient (Eppendorf, Germany). A PCR reaction with all reaction components without DNA or with non-specific DNA was always run as a negative control. Each reaction was run at least three times to check the reproducibility of the results. The PCR products were run on a 1.5% agarose gel, visualized under UV and documented by Liscap software (Pharmacia Biotech., USA).

### 3.7.7 Root-knot nematode

Population of *Meloidogyne incognita* was determined by Cobb's decanting and

sieving method (modified) followed by Baerman funnel technique (Southy, 1986). A composite soil sample was made by collecting the soil from three randomly selected pots on rhizosphere of five plants in each microplot in case of field trials. The soil was sifted through a coarse sieve. The soil sample (1 kg) was mixed in 5 litres of water in a plastic bucket. The soil-water mixture was stirred and then allowed to stand for 1-2 minutes. The suspension was decanted over a combination of 3 sieves (60, 200 and 500 mesh), the catch from the final sieve was carefully washed and transferred to a beaker.

A small coarse sieve with two layers of wet paper towels was kept in a Baermann funnel filled with water. The nematode suspension from the beaker was gently poured onto the sieve and allowed to stand overnight. The nematode juveniles because of the random and continuous movement migrate through the paper pores into the water and gradually settled down in the bottom of rubber tubing of the funnel. The nematode suspension recovered from the Baermann funnel was taken into a beaker and counted in a counting dish under a stereomicroscope.

### 3.7.8 Root-nodulation

When plants were two month old, three pots out of six were randomly selected and the plants were carefully uprooted to observe nodules. In microplots 5 plants were randomly uprooted from each pot/microplot to count root nodules. Care was taken to avoid root loss. Pink and healthy nodules were recognized as functional nodules, where as dark brown and degenerated ones as nonfunctional nodules.

### 3.7.9 Harvesting

At maturity pigeonpea plants were harvested from pots (3 plants / treatment) whereas in case of field trials, 10 plants from each microplot were randomly uprooted and the following parameters were determined.

1. Wilt incidence

2. Wilt severity

3. Root-knot severity

4. Nematode reproduction

5. Dry weight of plants

6. Weight of seeds/plant

7. Functional nodules/root system

8. Total nodules/root system

9. Nonfunctional nodules/root system

10. Soil population of pathogens and biocontrol agents

### 3.7.10 Wilt incidence and severity

Visual observations were made on two months old plants of pigeonpea to determine wilt severity and incidence (%) according to the following formulae:

$$\text{Wilt incidence (\%)} = \frac{\text{Number of wilted plants in a microplot}}{\text{Total number of plants in a microplot}} \times 100$$

$$\text{Wilt severity} = \frac{\text{Number of branches / twigs showing wilt symptom}}{\text{Total number of branches / twigs of a plant}} \times 100$$

### 3.7.11 Root-knot

Root system of the harvested plants at maturity were gently washed in slow stream of water. The roots were visually observed to count galls. To count egg masses, roots were treated with phloxine B solution (0.159 g/l) which gave stain to egg masses.

## 3.8 Statistical analysis

The observations taken from ten plants from a microplot were averaged and considered as one replicate. Since three microplots were maintained for each treatment, there were three replicates. In the pot culture experiment, 6 replicates were maintained for each treatment. The data was subjected to a three-factor analysis of variance. Nematodes were considered as one factor, fungus as second factor and cultivars as third factor. The data on wilt incidence, root-knot, soil population etc. was analyzed for two factors ANOVA. Critical difference (C.D) was calculated at $P \leq 0.05$ and $P \leq 0.01$ for all variables to compare individual treatments. The data has been presented in tabulated and graphical forms.

# Chapter-4

# RESULTS

## Experiment 1

### 4.1 Pot trial

**Interaction of root-knot nematode *Meloidogyne incognita* and wilt fungus *Fusarium udum* on pigeonpea germplasm.**

Interaction of *M. incognita* and *F. udum* was investigated on 25 cultivars of pigeonpea in 15 cm diameter clay pots filled with 2 kg sterilized field soil compost mixture (3:1). Inoculation with the pathogens was done by applying 1, 2 and 4 g fungus colonized seeds / kg soil and 500, 1000 and 2000 juveniles of *M. incognita* / kg soil.

### 4.2 Symptoms

#### 4.2.1 Fusarial wilt

Plants inoculated with wilt fungus *F. udum* expressed wilt symptoms. The plants showed mild chlorosis and stunted growth as first sign of the disease symptom at seedling stage. The seedlings which escaped early infection developed mild chlorosis and stunted growth at one month of age. At a later stage, leaves / branches wilted, drooped and dried. Plants expressed wilt symptoms at all the three inoculum levels (1, 2, 4 g) of fungus. The wilt symptoms expressed by pigeonpea cultivars increased with the increase in initial inoculum level of wilt fungus *F. udum* in soil (Fig.1). The wilt severity increased the highest at 4g inoculum level of *F. udum* followed by 2g and 1g in all the cultivars tested. When 1g wilt fungus was combined with 1000 $J_2$ of *M. incognita* all the cultivars expressed wilt symptoms whereas wilt symptoms expressed in cvs. ICP8863, ICP8859 and ICP89049 was significant at $P \leq 0.05$. All the cultivars showed wilt symptoms significantly ($P \leq 0.01$) when 1 g wilt fungus was applied concomitantly with 2000 $J_2$ of *M. incognita* (Table 1).

#### 4.2.2 Root-knot symptoms

On the roots of the plants specific symptoms were discernibly found in the form of knot. The galls were small in size. Root system of cv.CO6 showed highest number of galls followed by Pusa 855 (Table 2, Fig.2) in the soil inoculated with 500 juvenile of *M. incognita* initially. Lowest number of galls per root system was found in cv. ICP 8863 and

Table 1. Effect of inoculations with *Fusarium udum* singly and concomitantly with *Meloidogyne incognita* on wilt severity (%) in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | | | | | 15.8 | 26.3 (66.3) | 29.6 (87.0) | 44.7 (182.6) | 22.2 | 29.9 (34.7) | 44.3 (99.7) | 55.2 (149.0) | 26.0 | 36.7 (41.3) | 54.7 (110.3) | 60.7 (33.2) |
| Manak | | | | | 13.5 | 24.0 (77.4) | 28.0 (107.0) | 39.1 (189.0) | 20.0 | 28.0 (40.0) | 39.0 (95.0) | 44.2 (121.0) | 24.1 | 34.1 (41.3) | 48.0 (99.1) | 48.5 (101.0) |
| AL 201 | | | | | 17.8 | 30.1 (69.1) | 34.4 (93.4) | 45.7 (156.7) | 23.1 | 34.7 (50.2) | 48.1 (108.0) | 57.3 (148.0) | 30.2 | 38.4 (27.4) | 56.9 (88.3) | 62.7 (107.5) |
| C 11 | | | | | 16.3 | 28.1 (72.1) | 32.7 (100.1) | 47.9 (193.3) | 22.9 | 32.5 (41.6) | 47.6 (107.6) | 55.7 (142.9) | 27.9 | 37.5 (34.4) | 56.1 (101.2) | 61.0 (118.9) |
| Sarvodaya | | | | | 14.9 | 20.5 (37.4) | 27.2 (83.0) | 40.1 (169.6) | 19.1 | 27.0 (41.2) | 40.6 (112.4) | 45.8 (139.6) | 22.8 | 37.5 (64.7) | 45.3 (99.1) | 51.5 (126.0) |
| ICPL 87 | | | | | 18.6 | 30.6 (64.7) | 36.3 (95.5) | 49.8 (167.7) | 23.6 | 36.0 (52.9) | 50.0 (112.1) | 57.9 (145.7) | 30.7 | 40.2 (30.7) | 57.6 (87.3) | 65.0 (111.6) |
| CO 6 | | | | | 18.6 | 31.1 (67.2) | 38.1 (105.0) | 50.5 (172.0) | 23.6 | 37.8 (60.5) | 50.3 (113.4) | 59.0 (150.2) | 31.4 | 42.5 (35.4) | 59.4 (89.1) | 66.4 (111.4) |
| GAUT 001E | | | | | 19.6 | 31.3 (59.3) | 40.2 (104.6) | 50.9 (159.3) | 25.2 | 39.9 (58.0) | 50.5 (100.2) | 59.7 (136.7) | 31.0 | 43.9 (41.5) | 60.1 (94.0) | 69.8 (125.2) |
| GT 100 | | | | | 18.8 | 31.1 (65.8) | 39.1 (108.4) | 50.2 (167.0) | 24.5 | 39.5 (61.1) | 50.5 (106.1) | 59.5 (142.9) | 30.1 | 43.4 (40.2) | 60.1 (94.0) | 69.8 (125.4) |
| Pusa 84 | | | | | 19.8 | 33.2 (67.9) | 40.6 (105.5) | 52.0 (163.0) | 29.5 | 40.8 (38.4) | 52.2 (77.0) | 63.1 (114.0) | 33.0 | 44.8 (35.8) | 64.0 (94.0) | 72.6 (120.1) |
| AL 15 | | | | | 22.4 | 33.3 (48.7) | 41.6 (85.6) | 55.0 (145.7) | 29.0 | 41.8 (44.0) | 54.7 (88.7) | 63.4 (118.7) | 33.3 | 45.1 (35.7) | 62.9 (89.0) | 74.1 (123.0) |
| Pusa 855 | | | | | 15.2 | 23.1 (52.2) | 28.9 (90.3) | 41.1 (170.4) | 19.3 | 29.0 (49.9) | 40.7 (110.1) | 48.3 (149.5) | 23.4 | 35.0 (49.4) | 48.7 (108.0) | 51.8 (121.1) |
| Pusa 33 | | | | | 15.5 | 26.6 (71.5) | 29.4 (89.5) | 44.0 (184.0) | 20.1 | 29.6 (47.4) | 43.8 (17.8) | 55.2 (175.0) | 26.6 | 36.4 (36.7) | 54.9 (106.1) | 58.7 (120.3) |
| Paras | | | | | 16.0 | 27.0 (68.6) | 31.7 (97.8) | 47.8 (198.0) | 22.7 | 32.0 (41.0) | 47.7 (110.0) | 55.5 (144.5) | 26.8 | 37.3 (38.9) | 56.1 (109.1) | 59.5 (121.8) |
| AKT 8811 | | | | | 12.1 | 22.1 (82.6) | 27.1 (124.6) | 37.1 (206.6) | 18.2 | 27.1 (49.1) | 37.1 (104.2) | 41.0 (125.7) | 22.2 | 32.0 (44.1) | 41.1 (85.3) | 46.3 (108.6) |
| ICP 14722 | | | | | 6.7 | 16.2 (141.8) | 21.1 (215.4) | 30.1 (349.7) | 9.9 | 21.2 (114.1) | 30.0 (203.3) | 35.0 (254.2) | 12.0 | 26.2 (118.9) | 35.1 (193.5) | 40.1 (235.3) |
| ICP 8859 | | | | | 8.5 | 17.1 (101.2) | 20.1 (136.8) | 29.1 (242.4) | 11.1 | 20.1 (80.9) | 29.1 (161.5) | 34.1 (206.4) | 13.0 | 25.1 (93.6) | 34.1 (162.3) | 39.1 (200.8) |
| ICPL 89049 | | | | | 6.3 | 14.1 (123.8) | 18.1 (187.8) | 26.0 (312.7) | 8.6 | 18.1 (111.2) | 26.1 (204.9) | 32.0 (273.8) | 12.0 | 22.2 (84.2) | 32.1 (166.2) | 37.1 (207.4) |
| DPPA 85-13 | | | | | 6.9 | 15.1 (117.9) | 19.0 (175.2) | 26.0 (274.8) | 10.0 | 19.1 (91.0) | 26.1 (161.3) | 31.0 (210.0) | 12.6 | 22.2 (76.9) | 31.1 (147.2) | 35.6 (183.0) |
| ICPL 89048 | | | | | 7.8 | 16.5 (111.5) | 20.1 (157.3) | 28.1 (260.6) | 11.0 | 20.2 (83.9) | 28.2 (156.6) | 32.1 (192.1) | 13.5 | 24.1 (78.5) | 32.1 (137.6) | 37.1 (174.8) |
| ICPL 87119 | | | | | 8.1 | 17.1 (111.1) | 21.0 (159.3) | 29.1 (259.6) | 11.1 | 21.1 (90.9) | 29.0 (162.0) | 34.0 (207.4) | 14.1 | 25.1 (77.4) | 34.1 (141.1) | 39.1 (176.7) |
| AWR 74/15 | | | | | 6.1 | 16.1 (165.2) | 19.4 (219.6) | 27.2 (347.6) | 8.5 | 19.2 (126.2) | 28.1 (231.4) | 32.0 (276.8) | 12.1 | 24.1 (99.4) | 32.1 (166.0) | 37.1 (207.1) |
| ICP 8863 | | | | | 6.0 | 14.1 (136.7) | 18.0 (201.6) | 25.1 (319.9) | 8.0 | 17.5 (118.8) | 25.0 (212.9) | 29.1 (264.1) | 11.1 | 22.1 (100.3) | 29.0 (162.0) | 34.1 (208.0) |
| Bahar | | | | | 37.4 | 48.6 (30.0) | 54.4 (45.5) | 65.9 (76.3) | 43.2 | 54.4 (25.8) | 65.5 (51.5) | 78.2 (80.8) | 48.9 | 59.8 (22.4) | 78.4 (60.4) | 87.3 (78.6) |
| GCP 33 | | | | | 6.5 | 17.1 (163.1) | 20.5 (215.4) | 29.8 (358.0) | 13.1 | 20.0 (52.7) | 30.1 (130.0) | 33.3 (154.4) | 17.0 | 25.1 (47.6) | 33.1 (94.2) | 39.0 (129.0) |

CD $P \leq 0.05$ : 9.0

CD $P \leq 0.01$ : : 12.1

*F* - value

Fungus (df = 3) : 383.0[cd]

Nematode (df = 3) : 1066.1[cd]

Cultivar (df = 24) : 123.3[cd]

Fungus x Nematode (df = 9) : 10.7[cd]

Fungus x Cultivar (df = 9) : NS

Nematode x Cultivar (df = 9) : NS

Fungus x Nematode x Cultivars (df = 216) : NS

Figures in parenthesis are percent increase over $0J_2$ of *M. incognita*; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from control at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

Table 2. Effect of inoculations with *Meloidogyne incognita* singly and concomitantly with *Fusarium udum* on the number of root galls in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | | 35.0 | 40.0 | 44.0 | | 30.0 (14.3) | 33.0 (17.5) | 35.0 (20.4) | | 22.0 (37.1) | 26.0 (35.0) | 31.0 (29.6) | | 12.0 (65.7) | 15.0 (62.5) | 19.0 (56.8) |
| Manak | | 26.0 | 33.0 | 30.0 | | 22.0 (15.4) | 23.0 (30.3) | 26.0 (13.3) | | 17.0 (34.6) | 18.0 (45.5) | 20.0 (33.3) | | 8.0 (69.2) | 12.0 (63.6) | 15.0 (50.0) |
| AL 201 | | 55.0 | 60.0 | 63.0 | | 43.0 (21.8) | 48.0 (20.0) | 49.0 (22.2) | | 36.0 (35.0) | 39.0 (35.0) | 50.0 (20.6) | | 25.0 (55.0) | 30.0 (50.0) | 33.0 (47.6) |
| C 11 | | 55.0 | 59.0 | 63.0 | | 46.0 (16.4) | 50.0 (15.3) | 50.0 (20.6) | | 35.0 (36.0) | 38.0 (35.6) | 42.0 (33.3) | | 25.0 (55.0) | 28.0 (52.5) | 32.0 (49.2) |
| Sarvodaya | | 24.0 | 28.0 | 31.0 | | 20.0 (16.7) | 21.0 (25.0) | 23.0 (25.8) | | 15.0 (38.0) | 17.0 (39.3) | 17.0 (45.2) | | 7.0 (71.0) | 11.0 (60.7) | 14.0 (54.8) |
| ICPL 87 | | 52.0 | 57.0 | 60.0 | | 43.0 (17.3) | 47.0 (17.5) | 47.0 (21.7) | | 32.0 (38.0) | 36.0 (36.8) | 39.0 (35.0) | | 22.0 (58.0) | 26.0 (54.4) | 29.0 (51.7) |
| CO 6 | | 63.0 | 70.0 | 75.0 | | 53.0 (15.9) | 56.0 (20.0) | 58.0 (22.7) | | 39.0 (38.1) | 44.0 (37.1) | 49.0 (34.7) | | 27.0 (57.1) | 31.0 (55.7) | 35.0 (53.3) |
| GAUT 001E | | 57.0 | 61.0 | 65.0 | | 49.0 (14.0) | 52.0 (14.8) | 52.0 (20.0) | | 38.0 (33.3) | 45.0 (26.2) | 49.0 (24.6) | | 27.0 (52.6) | 31.0 (49.2) | 35.0 (46.2) |
| GT 100 | | 35.0 | 38.0 | 41.0 | | 30.0 (14.3) | 31.0 (18.4) | 33.0 (19.5) | | 20.0 (42.9) | 25.0 (34.2) | 27.0 (34.1) | | 10.0 (71.4) | 14.0 (63.2) | 17.0 (58.5) |
| Pusa 84 | | 31.0 | 35.0 | 38.0 | | 25.0 (19.4) | 25.0 (28.6) | 28.0 (26.3) | | 20.0 (35.5) | 20.0 (42.9) | 23.0 (39.5) | | 10.0 (67.7) | 13.0 (62.9) | 17.0 (55.3) |
| AL 15 | | 51.0 | 56.0 | 60.0 | | 41.0 (19.6) | 45.0 (19.6) | 47.0 (21.7) | | 32.0 (37.3) | 34.0 (39.3) | 37.0 (38.3) | | 22.0 (56.9) | 25.0 (55.4) | 29.0 (51.7) |
| Pusa 855 | | 61.0 | 66.0 | 71.0 | | 50.0 (18.0) | 53.0 (19.7) | 57.0 (19.7) | | 39.0 (36.1) | 41.0 (37.9) | 46.0 (35.2) | | 28.0 (54.1) | 31.0 (53.0) | 35.0 (50.7) |
| Pusa 33 | | 43.0 | 48.0 | 52.0 | | 33.0 (23.2) | 36.0 (25.0) | 39.0 (25.0) | | 25.0 (41.9) | 26.0 (45.8) | 30.0 (42.3) | | 15.0 (65.1) | 19.0 (60.4) | 22.0 (57.7) |
| Paras | | 45.0 | 49.0 | 53.0 | | 34.0 (24.4) | 38.0 (22.5) | 40.0 (24.5) | | 26.0 (42.2) | 27.0 (44.9) | 31.0 (41.5) | | 15.0 (66.7) | 18.0 (63.3) | 22.0 (58.5) |
| AKT 8811 | | 17.0 | 18.0 | 21.0 | | 13.0 (23.5) | 14.0 (22.2) | 15.0 (28.6) | | 9.0 (47.1) | 10.0 (44.4) | 12.0 (42.9) | | 5.0 (70.6) | 7.0 (61.1) | 9.0 (57.1) |
| ICP 14722 | | 32.0 | 33.0 | 49.0 | | 28.0 (12.5) | 30.0 (9.1) | 35.0 (28.6) | | 23.0 (28.1) | 24.0 (27.3) | 27.0 (44.9) | | 15.0 (53.1) | 18.0 (45.5) | 21.0 (57.1) |
| ICP 8859 | | 32.0 | 37.0 | 41.0 | | 29.0 (9.4) | 28.0 (24.3) | 31.0 (24.4) | | 20.0 (37.5) | 24.0 (35.1) | 27.0 (34.2) | | 11.0 (65.6) | 15.0 (59.5) | 18.0 (56.1) |
| ICPL 89049 | | 50.0 | 53.0 | 57.0 | | 40.0 (20.0) | 42.0 (20.7) | 45.0 (21.1) | | 30.0 (40.0) | 33.0 (37.7) | 37.0 (35.1) | | 21.0 (58.0) | 24.0 (54.7) | 28.0 (50.9) |
| DPPA 85-13 | | 20.0 | 22.0 | 25.0 | | 16.0 (20.0) | 18.0 (18.2) | 18.0 (28.0) | | 13.0 (35.0) | 15.0 (31.8) | 15.0 (40.0) | | 6.0 (70.0) | 10.0 (54.6) | 13.0 (48.0) |
| ICPL 89048 | | 47.0 | 51.0 | 54.0 | | 37.0 (21.3) | 39.0 (23.5) | 42.0 (22.2) | | 27.0 (42.6) | 31.0 (39.2) | 35.0 (35.2) | | 20.0 (57.4) | 22.0 (56.9) | 25.0 (53.7) |
| ICPL 87119 | | 31.0 | 35.0 | 38.0 | | 26.0 (16.1) | 27.0 (22.9) | 29.0 (23.7) | | 19.0 (38.7) | 21.0 940) | 24.0 (36.8) | | 11.0 (64.5) | 14.0 (60.0) | 17.0 (55.3) |
| AWR 74/15 | | 18.0 | 20.0 | 23.0 | | 11.0 (30.4) | 16.0 (20.0) | 16.0 (38.9) | | 11.0 (38.9) | 13.0 (35.0) | 13.0 (43.5) | | 5.0 (72.2) | 8.0 (60.0) | 10.0 (56.5) |
| ICP 8863 | | 18.0 | 20.0 | 23.0 | | 14.0 (22.2) | 16.0 (20.0) | 16.0 (30.4) | | 12.0 (33.3) | 12.0 (40.0) | 13.0 (43.5) | | 5.0 (72.2) | 9.0 (55.0) | 10.0 (56.5) |
| Bahar | | 39.0 | 45.0 | 51.0 | | 32.0 (18.0) | 33.0 (26.7) | 36.0 (29.4) | | 20.0 (48.7) | 25.0 (44.4) | 29.0 (43.1) | | 8.0 (79.5) | 13.0 (71.1) | 17.0 (66.7) |
| GCP 33 | | 40.0 | 43.0 | 46.0 | | 31.0 (22.5) | 33.0 (23.3) | 36.0 (21.7) | | 22.0 (45.0) | 26.0 (39.5) | 29.0 (37.0) | | 13.0 (67.5) | 17.0 (60.5) | 20.0 (56.5) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 7.1 |
| CD $P \leq 0.01$ | : : 9.6 |
| *F* - value | |
| Fungus (df = 3) | : $52.6^{ca}$ |
| Nematode (df = 3) | : $23.2^{ca}$ |
| Cultivar (df = 24) | : $228.1^{ca}$ |
| Fungus x Nematode (df = 9) | : $622.2^{ca}$ |
| Fungus x Cultivar (df = 9) | : NS |
| Nematode x Cultivar (df = 9) | : NS |
| Fungus x Nematode x Cultivars (df = 216) | : $3.1^{c}$ |

Figures in parenthesis are percent decrease over 500, 1000 and 2000 $J_2$ of *M. incognita* alone respectively; [a]Significantly different from control at $P \leq 0.05$; bSignificantly different from controlat $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not signific at $P \leq 0.05$

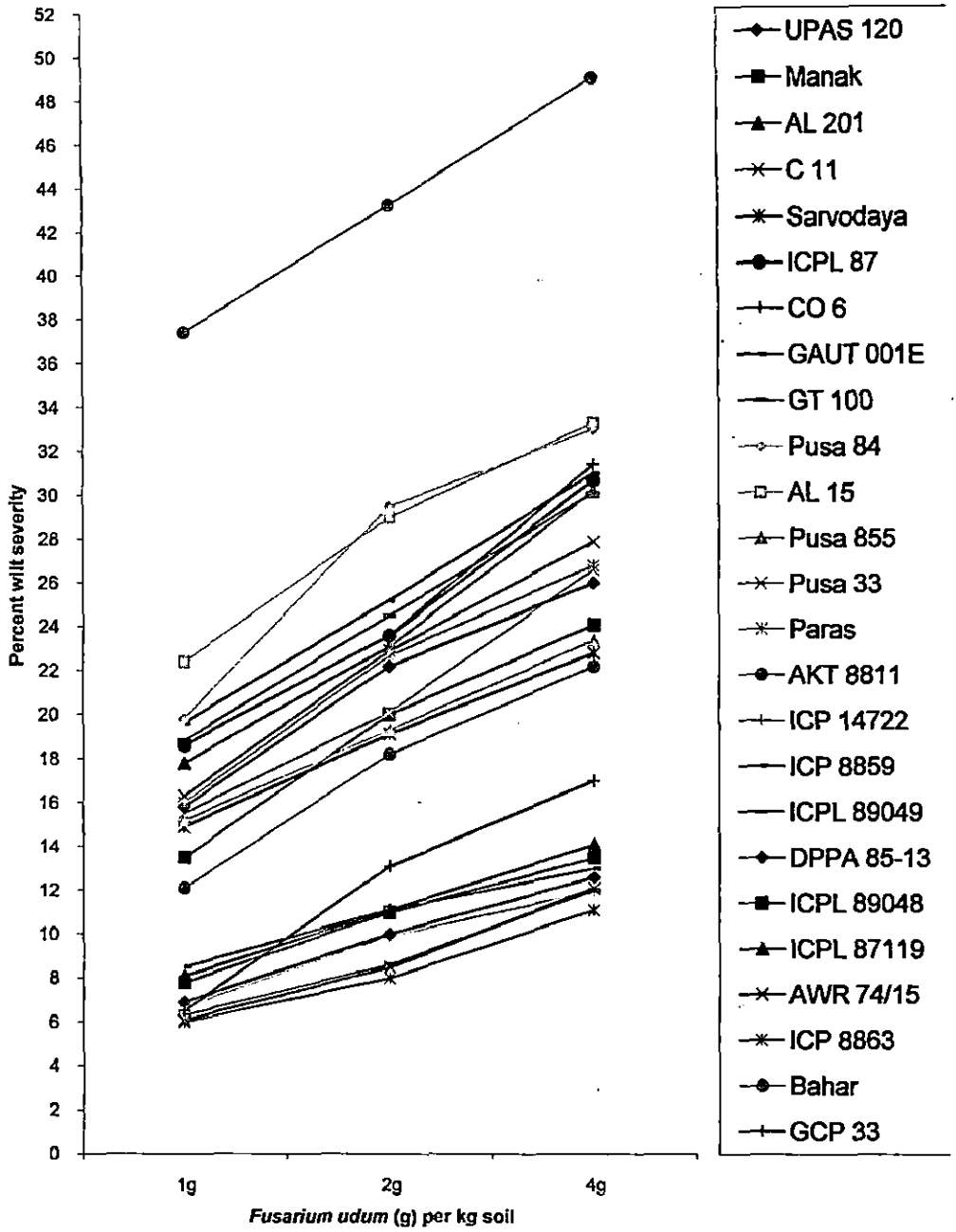


**Fig.1 Effect of inoculation with *Fusarium udum* on wilt severity (%) in pigeonpea under pot condition.**

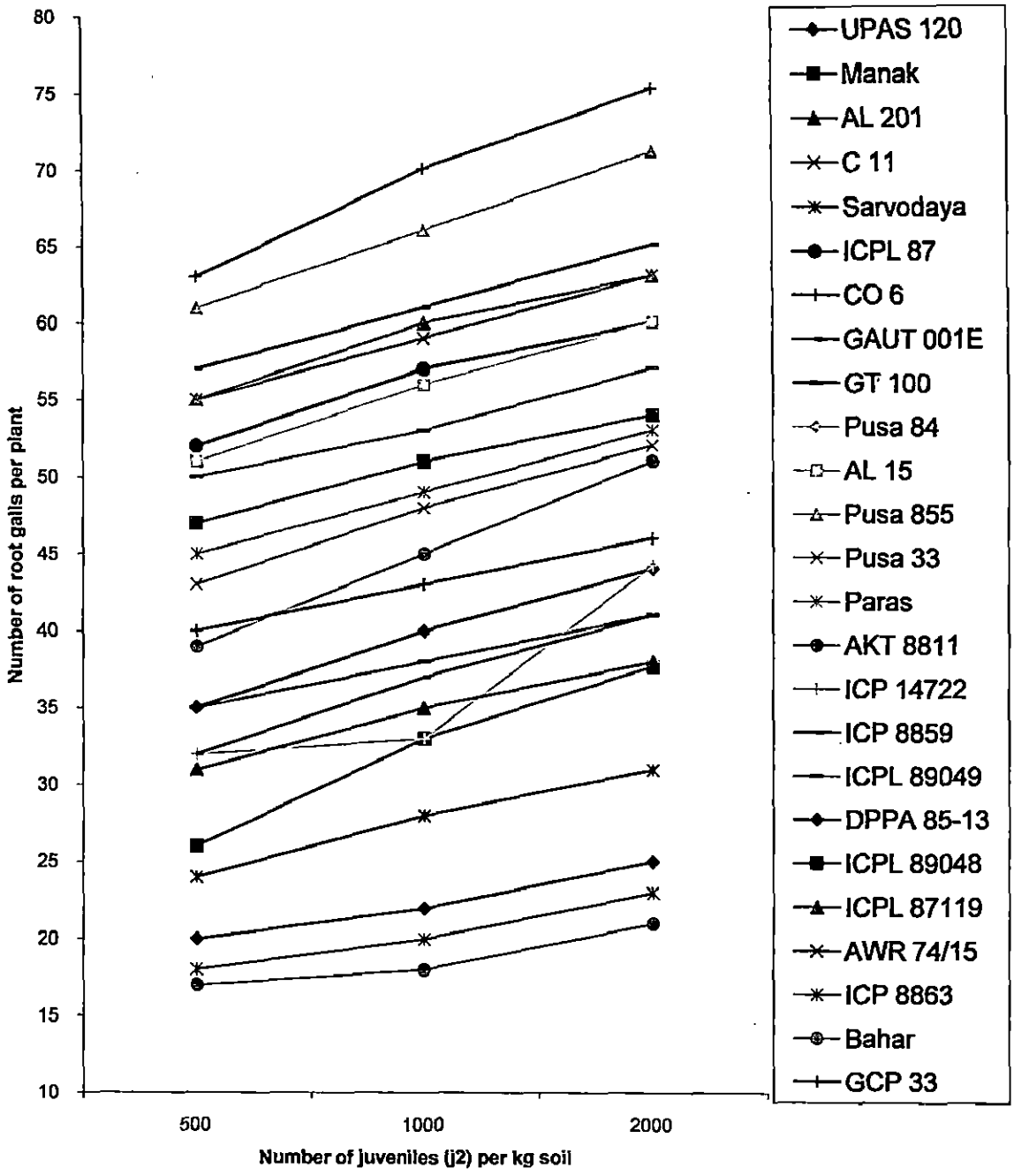


**Fig.2 Effect of inoculation with *Meloidogyne incognita* on the number of root galls in pigeonpea under pot culture condition.**

AWR 74/15 at this level. Highest number of galls per root system was recorded when initial inoculum level of *M. incognita* was 2000 juveniles alone. The gall number per root system was highest in cv. CO6 (75) followed by Pusa 855 (71). Lowest number of galls per root system was recorded in cv. AKT 8811(21) followed by ICP 8863 and AWR 74/15 (23 each). When 1g fungus was combined with 500 $J_2$ of *M. incognita* the cvs. CO6 and Pusa 855 recorded highest number of galls i.e. 53 and 50, respectively whereas lowest number of galls were observed in cvs. AWR74/15 and ICP8863 which was 11 and 14, respectively (Table 2). When the inoculum level of root-knot nematode was increased to 1000 $J_2$ and 2000 $J_2$ / kg soil at the same inoculum level of fungus (1 g) there was a slight increase in the number of galls in all the cultivars tested. However, when the inoculum level of wilt fungus was increased to 2 g there was a suppression in the number of galls at all the three levels of inoculum of root-knot nematodes (500, 1000 and 2000). The suppression of galls was further increased ($P \leq 0.01$) when the same inoculum level of root knot nematode was combined with 4g wilt fungus. Maximum suppression in galling was observed in cv. Bahar (79.5%) when 500 $J_2$ was applied contomitantly with 4g fungus whereas it was minimum in cv. GAUT001E (52.6%) (Table 2). Maximum suppression (66.7%) in galling was observed in cv. Bahar when 4g fungus was applied with 2000 $J_2$ of *M. incognita* whereas at the same combination it was minimum in GAUT001E (46.2%). Egg mass per root system was highest where initial soil inoculation was done with 2000 juveniles of *M. incognita* alone in all the cultivars (Table 3, Fig. 3). Greatest number of egg mass per root system was recorded in cv. CO6 which was 32, 51 and 69 at initial soil inoculum level of 500, 1000 and 2000 juveniles of *M. incognita* alone, respectively. However, it was minimum i.e. 10, 12 and 13 in case of cv. AWR 74/15 at 500, 1000 and 2000 juveniles of *M. incognita* alone, respectively. The highest suppression of egg mass formation in presence of wilt fungus was observed in cv. Bahar which showed 30, 50 and 85% suppression in the number of egg mass at 1, 2 and 4 g wilt fungus respectively with 500 $J_2$ (Table 3). At the above mentioned inoculum level of wilt fungus the egg mass suppression was 48, 62 and 79% respectively in presence of 1000 $J_2$ whereas in presence of 2000 $J_2$ the suppression in egg mass formation was 60.5, 69.8 and 79.1% respectively.

Table 3. Effect of inoculations with *Meloidogyne incognita* singly and concomitantly with *Fusarium udum* on the number of egg masses per root system in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | | 22.0 | 27.0 | 35.0 | | 16.0 (27.3) | 18.0 (433.3) | 20.0 (42.9) | | 13.0 (40.9) | 13.0 (51.9) | 14.0 (60.0) | | 7.0 (68.2) | 9.0 (66.7) | 12.0 (65.7) |
| Manak | | 17.0 | 18.0 | 24.0 | | 11.0 (35.3) | 13.0 (27.8) | 14.0 (41.7) | | 9.0 (47.1) | 10.0 (44.4) | 10.0 (58.3) | | 4.0 (76.5) | 7.0 (61.1) | 9.0 (62.5) |
| AL 201 | | 29.0 | 43.0 | 57.0 | | 22.0 (24.1) | 24.0 (44.2) | 27.0 (52.6) | | 18.0 (37.9) | 19.0 (55.8) | 19.0 (66.7) | | 11.0 (62.1) | 16.0 (62.8) | 17.0 (70.0) |
| C 11 | | 28.0 | 43.0 | 57.0 | | 21.0 (25.0) | 23.0 (46.5) | 27.0 (52.6) | | 18.0 (35.7) | 18.0 (58.1) | 19.0 (66.7) | | 11.0 (60.7) | 15.0 (65.1) | 17.0 (70.2) |
| Sarvodaya | | 15.0 | 17.0 | 21.0 | | 9.0 (40.0) | 12.0 (29.4) | 13.0 (38.1) | | 8.0 (46.7) | 9.0 (47.1) | 9.0 (57.1) | | 4.0 (73.3) | 7.0 (58.8) | 8.0 (61.9) |
| ICPL 87 | | 29.0 | 40.0 | 54.0 | | 21.0 (27.6) | 23.0 (42.5) | 26.0 (51.9) | | 17.0 (41.4) | 19.0 (52.5) | 21.0 61.1) | | 11.0 (62.1) | 13.0 (67.5) | 14.0 (74.1) |
| CO 6 | | 32.0 | 51.0 | 69.0 | | 25.0 (21.9) | 26.0 (49.0) | 31.0 (55.1) | | 19.0 (40.6) | 20.0 (60.8) | 22.0 (68.1) | | 12.0 (62.5) | 15.0 (70.6) | 18.0 (73.9) |
| GAUT 001E | | 30.0 | 44.0 | 59.0 | | 22.0 (26.7) | 23.0 (47.7) | 27.0 (54.2) | | 19.0 (36.7) | 21.0 (52.3) | 22.0 (62.7) | | 12.0 (60.0) | 16.0 (63.6) | 18.0 (69.5) |
| GT 100 | | 21.0 | 25.0 | 32.0 | | 15.0 (28.6) | 18.0 (28.0) | 18.0 (43.8) | | 12.0 (42.9) | 13.0 (48.0) | 14.0 (56.3) | | 6.0 (71.4) | 8.0 (68.0) | 11.0 (65.6) |
| Pusa 84 | | 19.0 | 19.0 | 29.0 | | 13.0 (31.6) | 15.0 (21.1) | 16.0 (44.8) | | 11.0 (42.1) | 12.0 (36.8) | 12.0 (58.6) | | 6.0 (68.4) | 8.0 (57.9) | 10.0 (65.5) |
| AL 15 | | 28.0 | 37.0 | 52.0 | | 22.0 (21.4) | 22.0 (40.5) | 23.0 (55.8) | | 17.0 (39.3) | 19.0 (48.6) | 19.0 (63.5) | | 11.0 (60.7) | 14.0 (62.2) | 15.0 (71.2) |
| Pusa 855 | | 31.0 | 48.0 | 65.0 | | 25.0 (19.4) | 27.0 (43.8) | 30.0 (53.8) | | 19.0 (38.7) | 20.0 (58.3) | 21.0 (67.7) | | 13.0 (58.1) | 15.0 (68.8) | 16.0 (75.4) |
| Pusa 33 | | 24.0 | 28.0 | 44.0 | | 18.0 (25.0) | 20.0 (28.6) | 21.0 (52.3) | | 13.0 (45.8) | 17.0 (39.3) | 18.0 (59.1) | | 9.0 (62.5) | 11.0 (60.7) | 13.0 (70.5) |
| Paras | | 24.0 | 30.0 | 45.0 | | 18.0 (25.0) | 20.0 (33.3) | 22.0 (51.1) | | 14.0 (41.7) | 17.0 (43.3) | 18.0 (60.0) | | 8.0 (66.7) | 11.0 (63.3) | 14.0 (68.9) |
| AKT 8811 | | 9.0 | 10.0 | 11.0 | | 7.0 (22.2) | 7.0 (30.0) | 8.0 (27.3) | | 5.0 (44.4) | 7.0 (30.0) | 7.0 (36.4) | | 3.0 (66.7) | 4.0 (60.0) | 5.0 (54.5) |
| ICP 14722 | | 21.0 | 27.0 | 41.0 | | 16.0 (23.8) | 18.0 (33.3) | 19.0 (53.7) | | 15.0 (28.6) | 15.0 (44.4) | 16.0 (61.0) | | 10.0 (52.4) | 12.0 (55.6) | 13.0 (68.3) |
| ICP 8859 | | 22.0 | 23.0 | 32.0 | | 16.0 (27.3) | 18.0 (21.7) | 29.0 (9.4) | | 13.0 (40.9) | 14.0 (39.1) | 14.0 (56.3) | | 12.0 (45.5) | 11.0 (52.2) | 7.0 (78.1) |
| ICPL 89049 | | 29.0 | 35.0 | 40.0 | | 23.0 (20.7) | 25.0 (28.6) | 26.0 (35.0) | | 21.0 (27.6) | 21.0 (40.0) | 22.0 (45.0) | | 14.0 (51.7) | 17.0 (51.4) | 18.0 (55.0) |
| DPPA 85-13 | | 12.0 | 13.0 | 15.0 | | 10.0 (16.7) | 10.0 (23.1) | 11.0 (26.7) | | 8.0 (33.3) | 8.0 (38.5) | 10.0 (33.3) | | 4.0 (66.7) | 7.0 (46.2) | 7.0 (53.3) |
| ICPL 89048 | | 28.0 | 31.0 | 46.0 | | 22.0 (21.4) | 24.0 (22.6) | 26.0 (43.5) | | 19.0 (32.1) | 19.0 (38.7) | 21.0 (54.3) | | 13.0 (53.6) | 15.0 (51.6) | 17.0 (63.0) |
| ICPL 87119 | | 20.0 | 21.0 | 28.0 | | 14.0 (30.0) | 17.0 (19.0) | 18.0 (35.7) | | 12.0 (40.0) | 13.0 (38.1) | 14.0 (50.0) | | 7.0 (65.0) | 10.0 (52.4) | 11.0 (60.7) |
| AWR 74/15 | | 10.0 | 12.0 | 13.0 | | 9.0 (10.0) | 9.0 (25.0) | 9.0 (30.8) | | 6.0 (40.0) | 7.0 (41.7) | 8.0 (38.5) | | 3.0 (70.0) | 6.0 (50.0) | 6.0 (53.8) |
| ICP 8863 | | 11.0 | 12.0 | 13.0 | | 9.0 (18.2) | 9.0 (25.0) | 9.0 (30.8) | | 6.0 (45.5) | 7.0 (41.7) | 8.0 (38.5) | | 3.0 (72.7) | 6.0 (50.0) | 6.0 (53.8) |
| Bahar | | 20.0 | 29.0 | 43.0 | | 14.0 (30.0) | 15.0 (48.3) | 17.0 (60.5) | | 10.0 (50.0) | 11.0 (62.1) | 13.0 (69.8) | | 3.0 (85.0) | 6.0 (79.3) | 9.0 (79.1) |
| GCP 33 | | 25.0 | 26.0 | 38.0 | | 20.0 (20.0) | 20.0 (23.1) | 22.0 ) | | 14.0 (44.0) | 15.0 (42.3) | 17.0 (55.3) | | 8.0 (68.0) | 12.0 (53.8) | 13.0 (65.8) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 4.9 |
| CD $P \leq 0.01$ | : : 6.6 |
| $F$ - value | |
| Fungus (df = 3) | : 977.0[ca] |
| Nematode (df = 3) | : 153.52[ca] |
| Cultivar (df = 24) | : 159.4[ca] |
| Fungus x Nematode (df = 9) | : 584.8[ca] |
| Fungus x Cultivar (df = 9) | : 3.18 [c] |
| Nematode x Cultivar (df = 9) | : 15.9[ca] |
| Fungus x Nematode x Cultivars (df = 216) | : 5.0[c] |

Figures in parenthesis are percent decrease over control; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from co at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

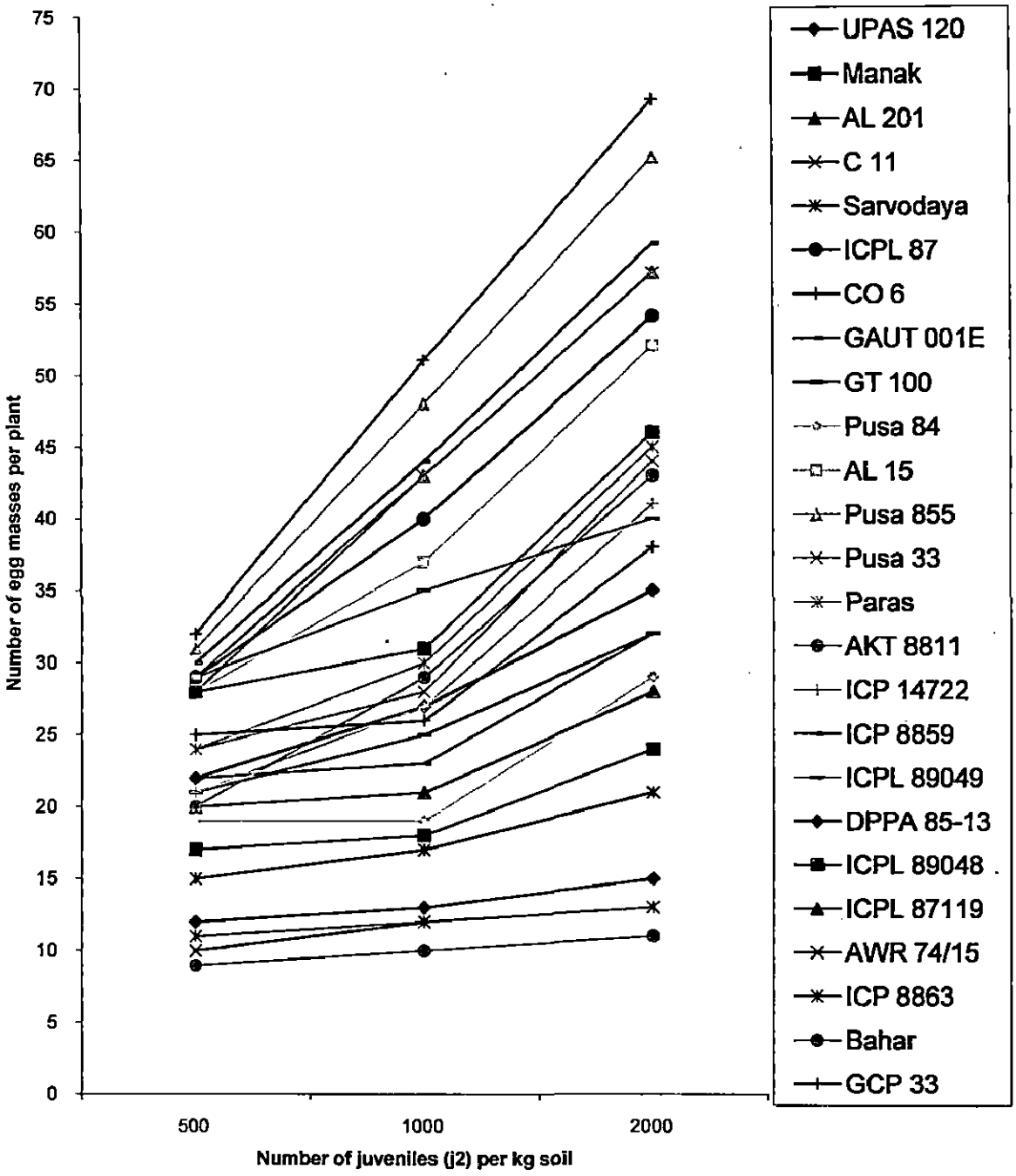


**Fig.3 Effect of inoculation with *Meloidogyne incognita* on the number of egg masses per root system in pigeonpea under pot culture condition.**

Table 4. Effect of inoculations with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on dry weight (g) of pigeonpea seedlings under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | 1.8 | 1.7 (5.6) | 1.6 (11.8) | 1.5 (17.4) | 1.7 | 1.5 (15.1) | 1.4 (20.4) | 1.2 (30.8) | 1.7 | 1.4 (18.5) | 1.2 (29.2) | 1.1 (34.5) | 1.5 | 1.3 (16.4) | 1.1 (27.6) | 1.0 (32.8) |
| Manak | 1.8 | 1.7 (4.3) | 1.7 (8.7) | 1.6 (14.7) | 1.7 | 1.6 (9.2) | 1.5 (14.4) | 1.3 (27.1) | 1.7 | 1.5 (13.3) | 1.3 (26.7) | 1.2 (32.0) | 1.6 | 1.4 (15.4) | 1.2 (27.8) | 1.1 (32.7) |
| AL 201 | 1.7 | 1.5 (6.6) | 1.5 (11.4) | 1.4 (18.0) | 1.6 | 1.3 (15.2) | 1.3 (19.6) | 1.1 (30.3) | 1.5 | 1.3 (16.6) | 1.2 (27.8) | 1.0 (35.8) | 1.4 | 1.2 (18.6) | 0.9 (34.5) | 0.8 (41.4) |
| C 11 | 1.7 | 1.6 (4.1) | 1.5 (9.4) | 1.4 (15.9) | 1.6 | 1.4 (11.0) | 1.3 (17.2) | 1.2 (28.8) | 1.5 | 1.4 (12.3) | 1.2 (24.5) | 1.1 (30.3) | 1.5 | 1.3 (14.3) | 1.1 (26.5) | 0.9 (36.0) |
| Sarvodaya | 1.8 | 1.7 (4.4) | 1.6 (9.3) | 1.6 (14.3) | 1.8 | 1.5 (13.0) | 1.4 (18.1) | 1.3 (27.1) | 1.7 | 1.5 (14.1) | 1.3 (24.7) | 1.2 (30.0) | 1.6 | 1.4 (13.8) | 1.2 (25.8) | 1.1 (32.7) |
| ICPL 87 | 1.8 | 1.7 (4.0) | 1.6 (9.1) | 1.5 (15.9) | 1.7 | 1.4 (14.7) | 1.3 (21.2) | 1.2 (31.8) | 1.6 | 1.4 (16.6) | 1.1 (29.4) | 1.1 (34.4) | 1.5 | 1.2 (17.8) | 1.1 (29.6) | 1.0 (35.5) |
| CO 6 | 1.8 | 1.7 (3.3) | 1.6 (8.4) | 1.5 (14.0) | 1.7 | 1.5 (10.9) | 1.5 (16.1) | 1.3 (27.6) | 1.7 | 1.5 (12.0) | 1.2 (25.3) | 1.1 (31.9) | 1.6 | 1.3 (14.0) | 1.1 (26.7) | 1.0 (33.8) |
| GAUT 001E | 1.9 | 1.8 (3.2) | 1.8 (6.3) | 1.7 (12.1) | 1.9 | 1.7 (9.7) | 1.6 (15.6) | 1.4 (26.9) | 1.8 | 1.6 (10.7) | 1.4 (23.6) | 1.3 (29.2) | 1.7 | 1.5 (13.6) | 1.3 (24.8) | 1.1 (31.9) |
| GT 100 | 1.9 | 1.8 (3.7) | 1.7 (8.0) | 1.6 (13.4) | 1.8 | 1.6 (9.9) | 1.5 (15.4) | 1.3 (25.8) | 1.7 | 1.5 (10.9) | 1.4 (21.3) | 1.3 (27.6) | 1.6 | 1.5 (10.3) | 1.3 (22.4) | 1.1 (30.3) |
| Pusa 84 | 1.9 | 1.9 (2.6) | 1.8 (6.2) | 1.7 (10.9) | 1.9 | 1.7 (10.1) | 1.6 (14.9) | 1.4 (24.5) | 1.8 | 1.6 (11.7) | 1.4 (20.6) | 1.3 (26.7) | 1.7 | 1.5 (11.2) | 1.3 (21.2) | 1.2 (28.2) |
| AL 15 | 1.8 | 1.7 (2.8) | 1.7 (6.7) | 1.6 (11.1) | 1.7 | 1.6 (9.8) | 1.5 (15.5) | 1.3 (26.4) | 1.7 | 1.5 (10.8) | 1.3 (22.7) | 1.2 (28.7) | 1.6 | 1.4 (13.3) | 1.2 (24.0) | 1.1 (31.6) |
| Pusa 855 | 1.7 | 1.6 (4.1) | 1.5 (9.5) | 1.4 (14.2) | 1.6 | 1.5 (10.4) | 1.4 (14.6) | 1.2 (26.8) | 1.6 | 1.4 (11.5) | 1.2 (22.3) | 1.1 (28.7) | 1.5 | 1.3 (12.1) | 1.1 (23.5) | 1.0 (32.2) |
| Pusa 33 | 1.7 | 1.6 (3.6) | 1.5 (7.7) | 1.5 (13.1) | 1.6 | 1.4 (12.2) | 1.3 (18.9) | 1.1 (29.9) | 1.6 | 1.3 (14.0) | 1.2 (25.4) | 1.1 (31.8) | 1.5 | 1.2 (16.8) | 1.1 (26.8) | 1.0 (34.9) |
| Paras | 1.7 | 1.7 (2.9) | 1.6 (6.9) | 1.5 (12.1) | 1.7 | 1.5 (10.2) | 1.4 (15.6) | 1.2 (26.3) | 1.5 | 1.4 (11.8) | 1.2 (16.2) | 1.1 (27.4) | 1.5 | 1.3 (12.6) | 1.1 (26.5) | 1.0 (33.8) |
| AKT 8811 | 1.8 | 1.7 (5.1) | 1.6 (9.6) | 1.5 (14.2) | 1.7 | 1.5 (12.3) | 1.4 (18.1) | 1.2 (28.6) | 1.7 | 1.4 (15.7) | 1.2 (26.5) | 1.1 (32.5) | 1.6 | 1.3 (16.6) | 1.1 (28.7) | 1.1 (33.8) |
| ICP 14722 | 3.1 | 3.1 (1.9) | 3.0 (4.5) | 2.9 (8.6) | 3.1 | 2.9 (8.6) | 2.8 (11.8) | 2.5 (19.4) | 3.1 | 2.8 (11.2) | 2.5 (19.5) | 2.4 (24.0) | 3.1 | 2.7 (15.1) | 2.4 (23.1) | 2.2 (28.5) |
| ICP 8859 | 3.2 | 3.1 (3.1) | 3.0 (6.5) | 2.9 (9.6) | 3.2 | 2.9 (8.4) | 2.8 (11.8) | 2.6 (19.2) | 3.2 | 2.8 (12.4) | 2.6 (19.9) | 2.4 (25.2) | 3.2 | 2.7 (16.1) | 2.4 (23.9) | 2.3 (29.8) |
| ICPL 89049 | 3.2 | 3.1 (3.1) | 3.0 (7.2) | 2.9 (10.6) | 3.2 | 2.9 (10.0) | 2.8 (14.1) | 2.5 (21.6) | 3.2 | 2.8 (13.7) | 2.5 (21.9) | 2.4 (25.6) | 3.2 | 2.7 (17.5) | 2.3 (25.7) | 2.3 (29.1) |
| DPPA 85-13 | 3.1 | 3.0 (3.2) | 2.9 (6.1) | 2.8 (9.7) | 3.1 | 2.8 (10.0) | 2.7 (12.3) | 2.5 (20.0) | 3.1 | 2.7 (12.9) | 2.5 (20.6) | 2.3 (25.5) | 3.1 | 2.6 (15.3) | 2.3 (24.7) | 2.1 (30.2) |
| ICPL 89048 | 3.1 | 3.1 (0.6) | 3.0 (3.9) | 2.9 (6.8) | 3.0 | 2.9 (7.1) | 2.7 (11.6) | 2.5 (19.0) | 2.9 | 2.8 (12.9) | 1.8 (42.3) | 2.4 (25.2) | 3.2 | 2.6 (16.8) | 2.4 (24.4) | 2.2 (29.1) |
| ICPL 87119 | 3.2 | 3.1 (1.9) | 3.0 (5.1) | 2.9 (8.9) | 3.1 | 2.8 (9.5) | 2.7 (12.7) | 2.5 (20.6) | 3.1 | 2.8 (12.1) | 2.5 (21.6) | 2.3 (25.7) | 3.1 | 2.6 (16.6) | 2.3 (25.1) | 2.2 (29.9) |
| AWR 74/15 | 3.1 | 3.0 (2.3) | 2.9 (4.8) | 2.9 (7.7) | 3.1 | 2.9 (7.4) | 2.7 (11.3) | 2.5 (18.7) | 3.1 | 2.8 (10.6) | 2.5 (19.0) | 2.4 (22.6) | 3.1 | 2.6 (14.8) | 2.4 (22.3) | 2.3 (26.1) |
| ICP 8863 | 3.2 | 3.2 (1.9) | 3.1 (4.7) | 3.0 (8.1) | 3.2 | 3.0 (7.8) | 2.9 (10.9) | 2.6 (17.7) | 3.2 | 2.9 (10.6) | 2.6 (18.3) | 2.5 (23.0) | 3.2 | 2.8 (14.0) | 2.5 (22.4) | 2.3 (27.0) |
| Bahar | 3.2 | 3.2 (1.5) | 3.1 (4.6) | 3.0 (8.3) | 3.2 | 3.0 (6.3) | 2.9 (10.1) | 2.6 (18.2) | 3.1 | 2.8 (7.2) | 2.6 (15.0) | 2.4 (20.9) | 2.9 | 2.7 (7.8) | 2.4 (16.9) | 2.2 (24.1) |
| GCP 33 | 3.1 | 3.1 (2.9) | 2.9 (6.3) | 2.8 (9.5) | 3.1 | 2.9 (8.9) | 2.7 (13.6) | 2.5 (21.6) | 3.1 | 2.7 (12.4) | 2.5 (21.3) | 2.3 (26.1) | 3.1 | 2.6 (17.2) | 2.3 (25.2) | 2.2 (30.2) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 0.2 |
| CD $P \leq 0.01$ | : : 1.0 |
| *F*- value | |
| Fungus (df = 3) | : 426.2[cd] |
| Nematode (df = 3) | : 687.8[cd] |
| Cultivar (df = 24) | : 1022.8[cd] |
| Fungus x Nematode (df = 9) | : 25.8[cd] |
| Fungus x Cultivar (df = 9) | : NS |
| Nematode x Cultivar (df = 9) | : NS |
| Fungus x Nematode x Cultivars (df = 216) | : NS |



Figures in parenthesis are percent decrease over control; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from co at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

Table 5. Effect of inoculations with *Meloidogyne incognita* and *Fusarium udum* singly and concomitantly on yield (g) in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | 7.8 | 7.5 (3.8) | 6.8 (12.8) | 6.0 (23.1) | 7.5 | 6.0 (20.0) | 5.1 (320 | 3.8 (49.3) | 6.8 | 5.1 (25.0) | 3.8 (44.0) | 6.4 (5.9) | 6.0 | 4.5 (25.0) | 3.1 (48.3) | 2.5 (58.3) |
| Manak | 8.7 | 8.5 (2.3) | 7.9 (9.2) | 7.1 (18.4) | 8.5 | 7.1 (16.5) | 6.1 (28.2) | 4.5 (47.1) | 7.9 | 6.2 (21.5) | 4.6 (41.8) | 3.8 (51.9) | 7.2 | 5.4 (25.0) | 3.7 (48.6) | 3.0 (58.3) |
| AL 201 | 8.6 | 8.5 (1.2) | 7.7 (10.5) | 7.1 (17.4) | 8.5 | 7.1 (16.5) | 6.2 (27.10 | 4.7 (44.7) | 7.7 | 6.2 (19.5) | 4.5 (41.6) | 3.7 (52.0) | 7.1 | 5.4 (23.9) | 3.6 (49.3) | 3.0 (57.8) |
| C 11 | 8.2 | 7.9 (3.7) | 7.3 (11.0) | 6.5 (20.7) | 8.0 | 6.5 (18.7) | 5.6 (30.0) | 4.0 (50.0) | 7.2 | 5.6 (22.2) | 4.2 (41.7) | 3.4 (52.8) | 6.6 | 4.7 (28.8) | 3.5 (47.0) | 2.8 (57.6) |
| Sarvodaya | 8.4 | 8.0 (4.8) | 7.3 (13.1) | 6.4 (23.8) | 8.2 | 6.2 (24.4) | 5.5 (32.9) | 4.0 (51.2) | 7.3 | 5.6 (23.2) | 4.0 (45.2) | 3.4 (53.4) | 6.4 | 4.7 (26.6) | 3.3 (48.4) | 2.7 (57.8) |
| ICPL 87 | 8.3 | 7.9 (4.8) | 7.2 (13.3) | 6.3 (24.1) | 7.9 | 6.3 (20.2) | 5.5 (30.3) | 4.2 (46.8) | 7.2 | 5.4 (25.0) | 4.3 (40.3) | 3.5 (51.4) | 6.4 | 4.8 (25.0) | 3.5 (45.3) | 2.7 (57.8) |
| CO 6 | 8.2 | 7.9 (3.7) | 7.2 (12.2) | 6.2 (24.2) | 7.9 | 6.4 (19.0) | 5.5 (30.4) | 4.2 (46.8) | 7.2 | 5.5 (23.6) | 3.6 (50.0) | 3.1 (56.9) | 6.2 | 4.9 (21.0) | 3.0 (51.6) | 2.5 (59.7) |
| GAUT 001E | 8.9 | 8.6 (3.4) | 7.7 (13.5) | 7.0 (21.4) | 8.6 | 6.9 (19.8) | 6.3 (26.7) | 4.5 (47.7) | 7.7 | 6.3 (18.2) | 4.5 (41.6) | 3.8 (51.0) | 7.0 | 5.2 (25.7) | 3.8 (45.7) | 3.0 (57.1) |
| GT 100 | 8.3 | 7.8 (6.0) | 7.2 (13.3) | 6.6 (20.5) | 8.1 | 6.6 (18.5) | 5.9 (27.2) | 4.2 (48.2) | 7.2 | 5.9 (18.1) | 4.1 (43.1) | 3.5 (51.4) | 6.5 | 5.0 (23.1) | 3.5 (46.2) | 2.8 (56.9) |
| Pusa 84 | 8.0 | 8.0 (5.0) | 7.3 (8.8) | 6.5 (18.8) | 7.9 | 6.6 (16.5) | 5.7 (27.9) | 4.2 (46.8) | 7.3 | 5.7 (21.9) | 4.2 (42.5) | 3.4 (53.4) | 6.4 | 5.0 (21.9) | 3.4 (46.9) | 2.6 (59.4) |
| AL 15 | 8.6 | 8.4 (2.3) | 7.7 (10.5) | 7.0 (18.6) | 8.4 | 7.0 (16.7) | 6.1 (27.4) | 4.4 (47.6) | 7.7 | 6.2 (19.5) | 4.4 (42.9) | 3.7 (51.9) | 7.1 | 5.2 (26.8) | 3.7 (47.9) | 3.0 (57.8) |
| Pusa 855 | 8.3 | 8.0 (3.6) | 7.5 (9.6) | 6.7 (19.9) | 8.0 | 6.7 (16.3) | 5.9 (26.3) | 4.4 (45.0) | 7.5 | 6.0 (20.0) | 4.5 (40.0) | 3.9 (48.0) | 6.7 | 5.1 (23.9) | 3.8 (43.3) | 3.2 (52.2) |
| Pusa 33 | 8.4 | 8.0 (4.8) | 7.4 (11.9) | 6.6 (21.4) | 8.0 | 6.7 (16.3) | 6.0 (25.0) | 4.4 (45.0) | 7.5 | 6.1 (18.7) | 4.4 (41.3) | 3.6 (52.0) | 6.7 | 5.2 (22.4) | 3.6 (46.3) | 2.8 (58.2) |
| Paras | 17.0 | 16.6 (2.4) | 15.8 (7.1) | 14.5 (14.7) | 16.9 | 14.7 (13.0) | 13.9 (17.8) | 12.0 (29.0) | 16.9 | 13.8 (18.3) | 11.9 (29.6) | 10.7 (36.7) | 16.7 | 12.7 (23.9) | 10.8 (35.3) | 9.3 (44.3) |
| AKT 8811 | 9.1 | 8.8 (3.3) | 8.4 (7.7) | 7.8 (14.3) | 9.0 | 8.0 (11.1) | 7.1 (21.1) | 5.9 (34.5) | 8.7 | 7.2 (17.2) | 5.9 (32.2) | 5.1 (41.4) | 8.2 | 6.5 920.7) | 5.0 (39.0) | 3.7 (54.9) |
| ICP 14722 | 8.7 | 8.5 (2.3) | 7.7 (11.5) | 7.0 (19.5) | 8.5 | 7.0 (17.7) | 6.1 (28.2) | 4.4 (48.2) | 7.7 | 6.2 (19.5) | 4.5 (41.6) | 3.9 (49.3) | 7.1 | 5.3 (25.4) | 3.9 (45.1) | 3.2 (54.9) |
| ICP 8859 | 16.4 | 15.8 (3.7) | 15.0 (8.5) | 13.7 (16.5) | 16.3 | 13.4 (17.8) | 12.4 (23.9) | 10.5 (35.6) | 16.1 | 12.5 (22.4) | 10.4 (35.4) | 9.1 (43.5) | 16.0 | 11.2 (30.0) | 9.0 (43.7) | 7.5 (53.1) |
| ICPL 89049 | 16.8 | 16.0 (4.8) | 15.0 (10.7) | 13.9 (17.3) | 16.8 | 13.6 (19.1) | 12.4 (26.2) | 10.3 (38.7) | 16.7 | 12.2 (27.0) | 10.2 (38.9) | 9.3 (44.3) | 16.4 | 11.3 (31.1) | 9.2 (43.9) | 8.0 (51.2) |
| DPPA 85-13 | 15.6 | 15.0 (3.9) | 14.1 (9.6) | 13.0 (16.7) | 15.6 | 13.0 (16.7) | 12.0 (23.1) | 9.9 (36.5) | 15.6 | 11.9 (23.7) | 9.8 (37.2) | 8.7 (44.2) | 15.6 | 10.8 (30.8) | 8.7 (44.2) | 7.5 (51.9) |
| ICPL 89048 | 16.4 | 15.7 (4.3) | 14.8 (9.8) | 13.5 (17.7) | 16.3 | 13.4 (17.8) | 12.5 (23.3) | 10.2 (37.4) | 16.3 | 12.6 (22.7) | 10.2 (37.4) | 9.4 (42.3) | 16.3 | 11.4 (30.1) | 9.4 (42.3) | 8.4 (48.5) |
| ICPL 87119 | 16.0 | 15.2 (5.0) | 14.3 (10.6) | 13.3 (16.9) | 16.0 | 13.5 (15.6) | 12.5 (21.9) | 10.2 (36.3) | 15.9 | 12.6 (20.8) | 10.2 (35.9) | 9.1 (42.8) | 15.9 | 11.4 (28.3) | 9.2 (42.1) | 7.7 (51.6) |
| AWR 74/15 | 15.8 | 15.4 (2.5) | 14.5 (8.2) | 13.4 (15.2) | 15.8 | 13.3 (15.8) | 12.3 (22.2) | 10.4 (34.2) | 15.8 | 12.4 (21.5 | 10.5 (33.5) | 9.5 (39.9) | 15.6 | 11.3 (27.6) | 9.5 (39.1) | 8.3 (46.8) |
| ICP 8863 | 16.7 | 16.4 (1.8) | 15.7 (6.0) | 14.6 (12.6) | 16.7 | 14.7 (12.0) | 13.9 (16.8) | 12.1 (27.5) | 16.7 | 13.8 (17.4) | 12.0 (28.1) | 10.9 )34.7) | 16.7 | 13.0 (22.2) | 10.9 (34.7) | 9.8 (41.3) |
| Bahar | 17.3 | 16.7 (3.5) | 16.0 (7.5) | 14.7 (15.0) | 15.2 | 14.4 (5.3) | 13.5 (11.2) | 11.0 (27.6) | 14.4 | 13.4 (4.3) | 11.1 (20.7) | 8.7 (37.9) | 11.0 | 12.2 (18.2) | 9.0 (18.2) | 6.5 (40.9) |
| GCP 33 | 16.8 | 16.0 (4.8) | 15.0 (10.7) | 14.0 (16.7) | 16.7 | 13.1 (21.6) | 12.0 (28.1) | 10.2 (38.9) | 16.7 | 12.1 (27.5) | 10.2 (38.9) | 9.0 (46.1 | 16.5 | 11.2 (32.1) | 9.0 (45.5) | 7.6 (53.9) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 1.6 |
| CD $P \leq 0.01$ | : 1; 2.1 |
| *F*- value | |
| Fungus (df = 3) | : 674.0[cd] |
| Nematode (df = 3) | : 978.23[cd] |
| Cultivar (df = 24) | : 602.9[cd] |
| Fungus x Nematode (df = 9) | : 37.2[cd] |
| Fungus x Cultivar (df = 9) | : 4.1[ca] |
| Nematode x Cultivar (df = 9) | : NS |
| Fungus x Nematode x Cultivars (df = 216) | : NS |

Figures in parenthesis are percent decrease over respective $0J_2$ of *M. incognita*; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from controlat $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

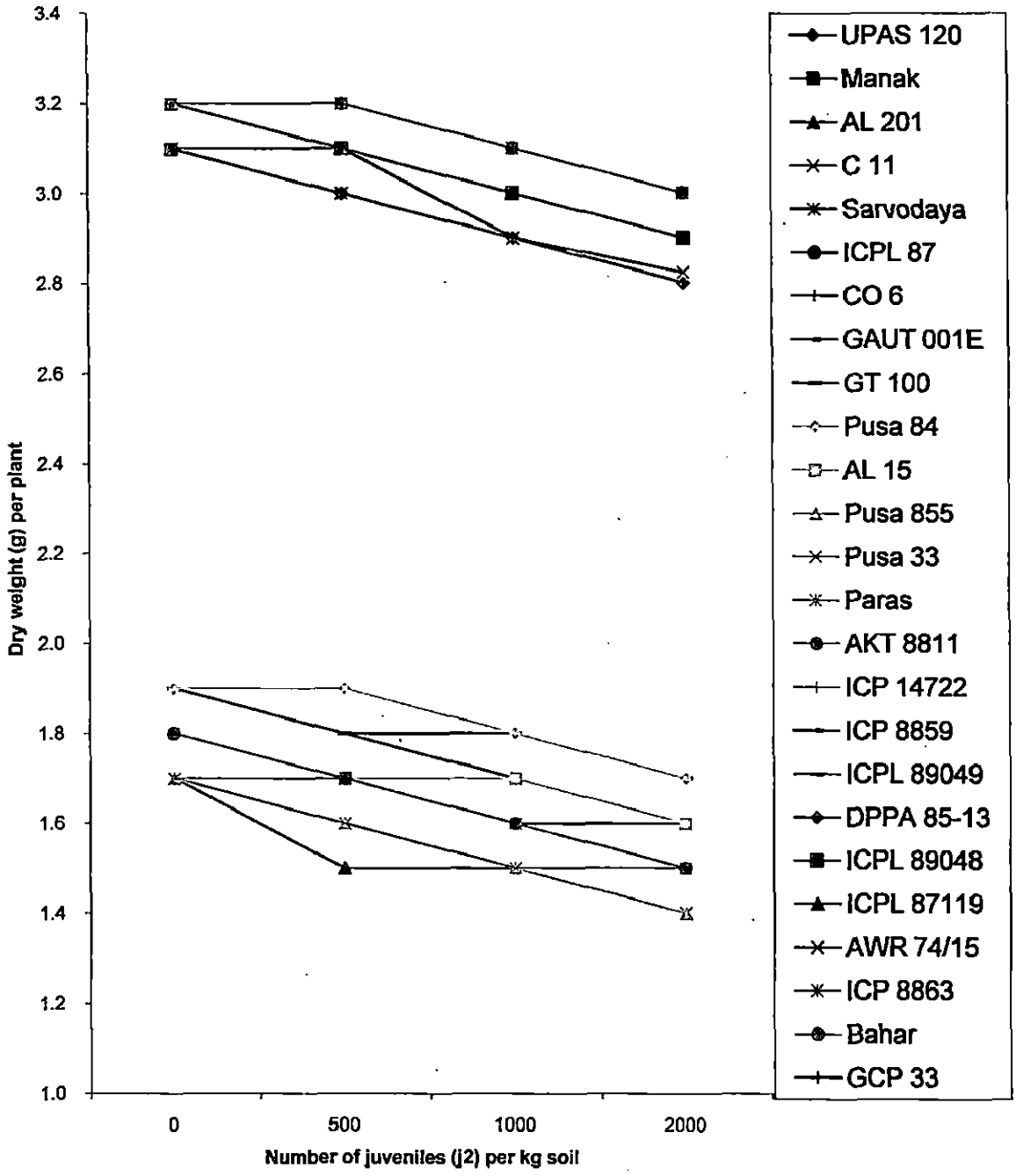


**Fig.4 Effect of inoculation with *Meloidogyne incognita* on dry weight (g) of pigeonpea seedlings under pot condition.**

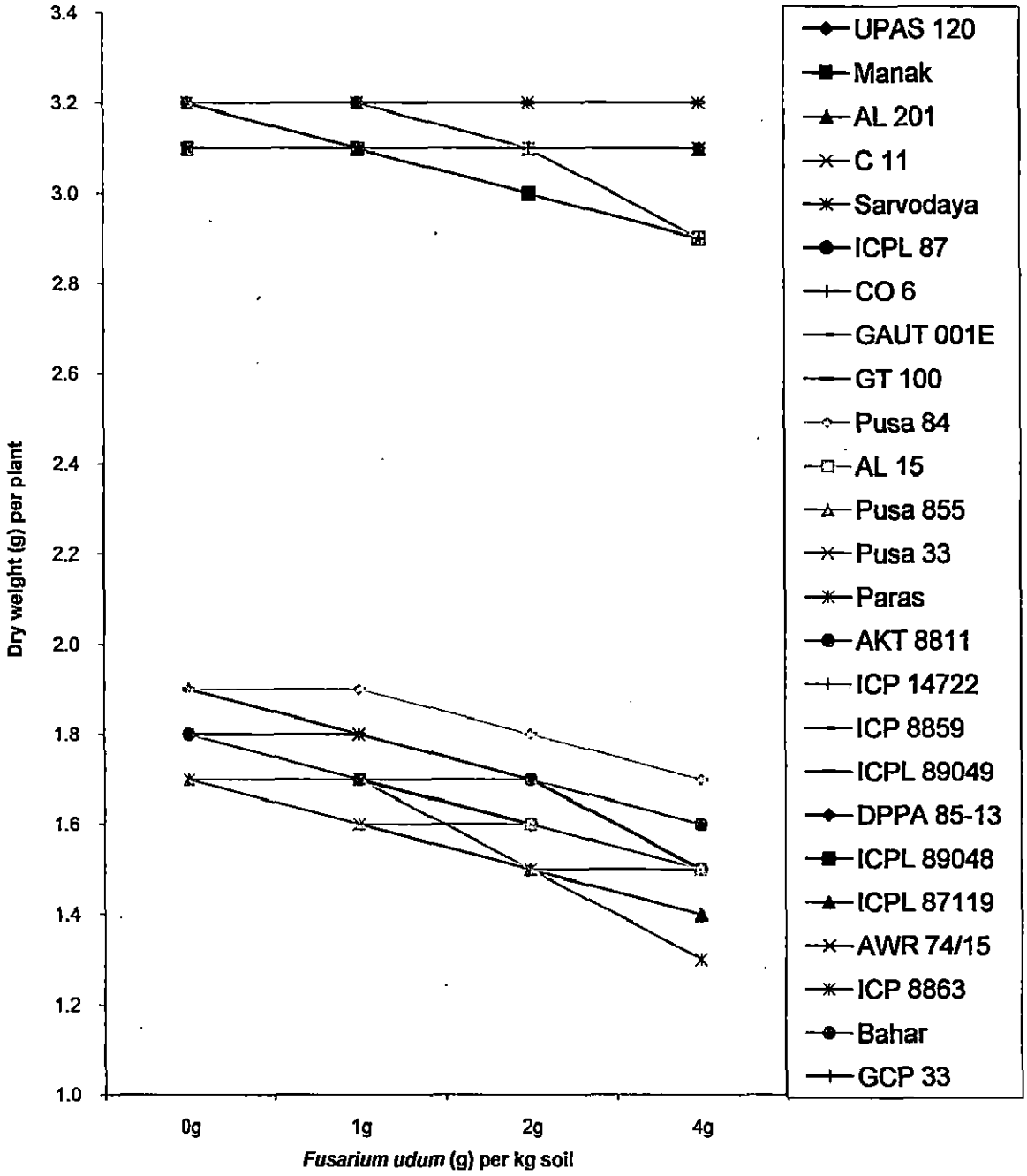


**Fig.5 Effect of inoculation with *Fusarium udum* on dry weight (g) of pigeonpea seedlings under pot condition.**

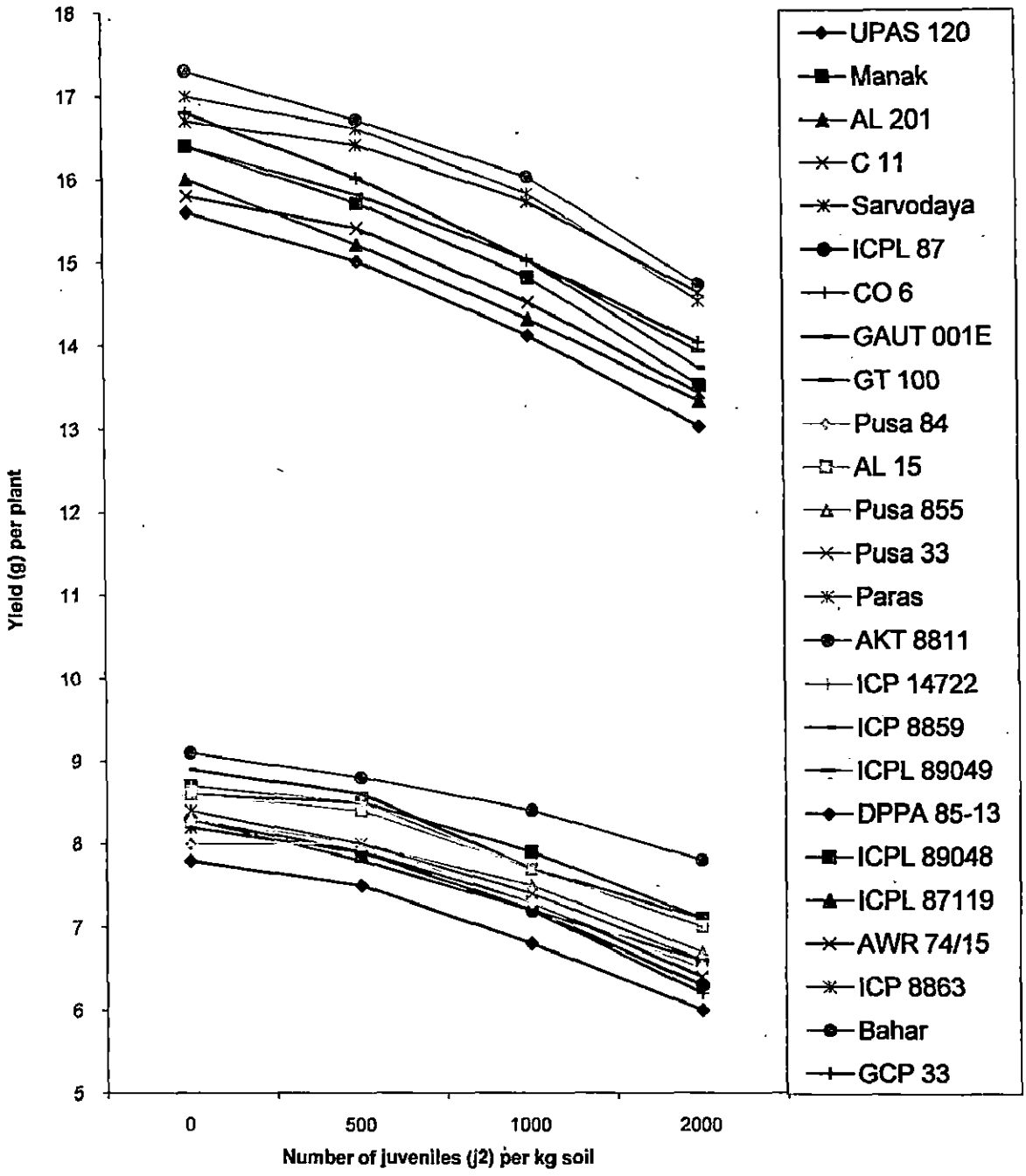


**Fig.6 Effect of inoculation with *Meloidogyne incognita* on yield (g) in pigeonpea under pot culture condition.**

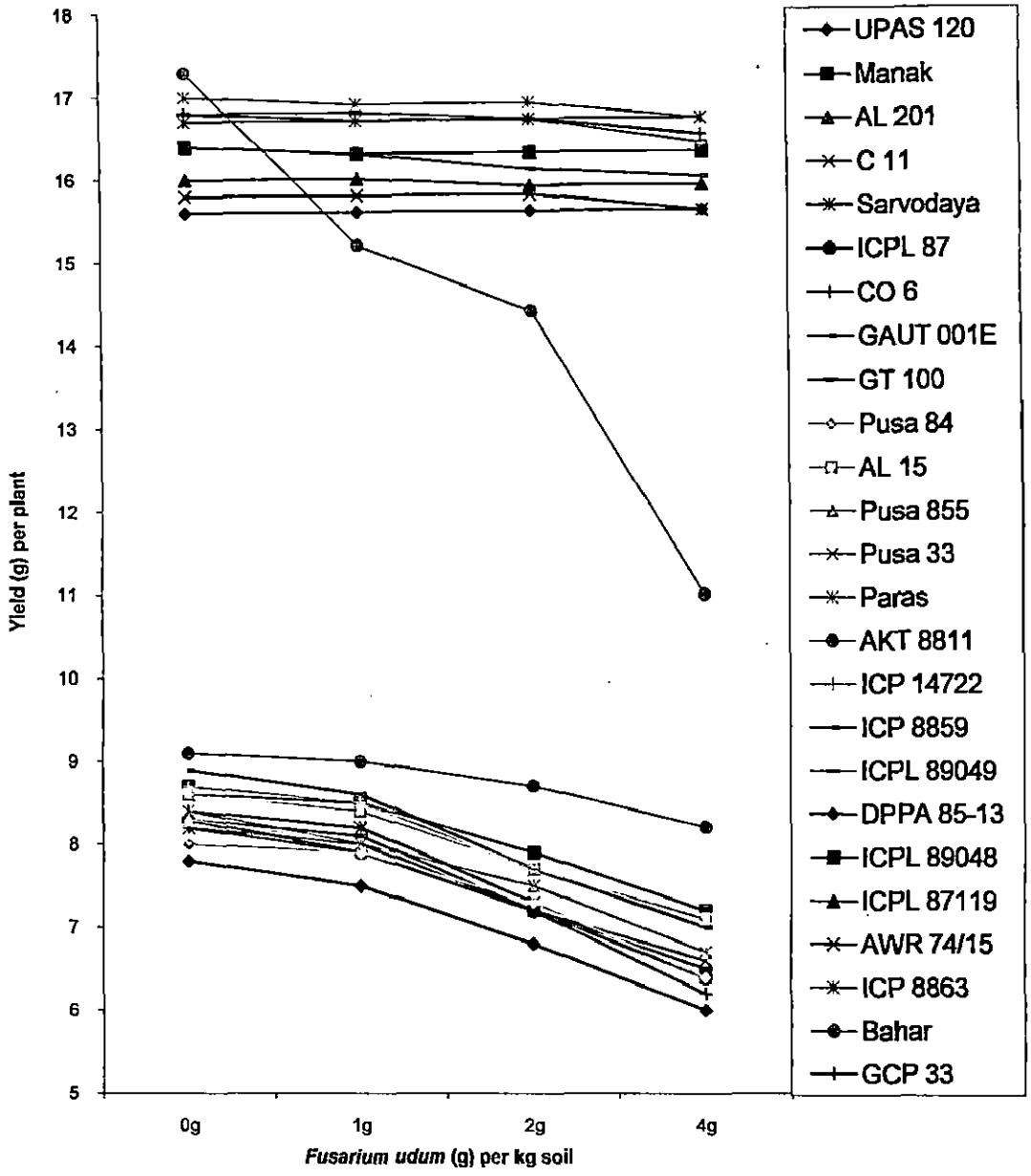


**Fig.7 Effect of inoculation with *Fusarium udum* on yield (g) in pigeonpea under pot condition.**

### 4.2.4 Root nodulation

An increase in initial inoculum level of juveniles of *M. incognita* alone in soil decreased the root nodulation in all the pigeonpea cultivars. Maximum decrease in root nodulation was recorded at 2000 followed by 1000 and 500 juveniles of *M. incognita* (Table 6, Fig. 8). The cvs. Pusa 33 showed the maximum (34.1%) decrease in root nodulation ($P \leq 0.05$) whereas the minimum decrease was observed in cv. ICP 8863 (15.9%) at 2000 initial inoculum level of juveniles of *M. incognita* in soil. Root nodulation was also affected at 1g, 2g and 4g initial inoculum level of wilt fungus *F. udum* in soil. Maximum reduction in root nodulation was recorded when 4g wilt fungus was inoculated in soil (Table 6, Fig. 9). However there was no affect of wilt fungus *F. udum* on root nodulation in cv. ICP8863. The functional nodules also decreased in all the cultivars of pigeonpea when 500, 1000 and 2000 juveniles of *M. incognita* alone was applied in soil (Table 7, Fig. 10). The same trend of decrease in functional nodules was observed with the increase in all the three i.e. 1, 2 and 4g inoculum level of wilt fungus *F. udum* in soil (Fig.11). number of non functional nodules increased in all the cultivars of pigeonpea when 500, 1000 and 2000 juveniles of *M. incognita* alone was applied in soil (Fog. 12). An increase in non functional nodules was observed in all the cultivars of pigeonpea at 1g, 2g and 4g initial inoculum level of wilt fungus *F. udum* in soil (Table 8, Fig. 13).

Interactive effect of root knot nematode *M. incognita* with wilt fungus *F. udum* was observed on the nodulation in all cultivars / accessions of pigeonpea. A decline in root nodules was observed when the inoculum level of root knot nematode was increased with the same dose of wilt fungus *F. udum* and vice-versa. However, at maximum inoculum level of both the organisms in combination resulted in greatest decline in total and functional nodulation and increase in non-function nodules in all the cultivars / accessions of pigeonpea. A combination of 500 $J_2$ of *M. incognita* with 1 g wilt fungus, *F. udum* resulted in greatest decrease ($P \leq 0.05$) in nodulation in cv. Bahar (27.9%) whereas it was lowest in case of Sarvodaya (14%) followed by AWR74/15 (15%) (Table 6). With the increase in fungus dose i.e. 2 g with the same inoculum level of nematode (500 $J_2$) 28% decrease in nodulation of Bahar was found. However, when 4g fungus was combined with 2000 $J_2$ of *M. incognita*. The decrease in nodulation was highest ($P \leq 0.01$) in cv. GT100 (69.4%) followed by cv. GAUT001E (66.7%). The lowest decrease was found in AL15 (53.9%) followed by AWR74/15 (54%). The decrease in functional nodule at the same inoculum level of wilt fungus and root knot simultaneously was 70-83% (Table 7). The

Table 6. Effect of inoculations with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on root nodulation in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | 42.0 | 39.0[a] (7.1) | 35.0[a] (16.7) | 31.0[a] (26.2) | 40.0 | 32.0[a] (20.0) | 29.0[a] (27.5) | 21.0[a] (47.5) | 36.0 | 28.0[a] (22.2) | 21.0[a] (41.5) | 16.0[a] (55.6) | 32.0 | 25.0[a] (21.9) | 16.0[a] (50.0) | 11.0[a] (65.6) |
| Manak | 47.0 | 45.0 (4.3) | 42.0[a] (10.6) | 38.0[a] (19.2) | 45.0 | 37.0[a] (17.8) | 28.7[a] (36.3) | 24.0[a] (46.7) | 42.0 | 33.0[a] (21.4) | 23.0[a] (45.2) | 22.3[a] (46.8) | 38.0 | 28.0[a] (26.3) | 20.0[a] (47.4) | 14.0[a] (63.2) |
| AL 201 | 45.0 | 43.0 (4.4) | 39.0[a] (13.3) | 35.0[a] (22.2) | 44.0 | 34.0[a] (22.7) | 30.0[a] (31.8) | 21.0[a] (52.3) | 39.0 | 29.0[a] (25.6) | 21.0[a] (46.2) | 17.0[a] (56.4) | 30.7 | 25.0[a] (18.5) | 17.0[a] (44.6) | 13.0[a] (57.6) |
| C 11 | 46.0 | 43.0[a] (6.5) | 39.0[a] (15.2) | 33.0[a] (28.3) | 44.0 | 33.0[a] (25.0) | 28.0[a] (36.4) | 19.0[a] (56.8) | 39.0 | 28.0[a] (28.2) | 18.0[a] (53.9) | 14.0[a] (64.1) | 34.0 | 23.0[a] (32.4) | 14.0[a] (58.8) | 10.0[a] (70.6) |
| Sarvodaya | 48.0 | 46.0 (4.2) | 42.0[a] (12.5) | 37.0[a] (22.9) | 43.0 | 37.0[a] (14.0) | 33.0[a] (23.3) | 25.0[a] (41.8) | 40.0 | 33.0[a] (17.5) | 24.0[a] (40.0) | 18.0[a] (55.0) | 35.0 | 29.0[a] (17.1) | 18.0[a] (48.6) | 14.0[a] (60.0) |
| ICPL 87 | 45.0 | 43.0 (4.4) | 39.0[a] (13.3) | 34.0[a] (24.4) | 43.0 | 34.0[a] (20.9) | 30.0[a] (30.2) | 21.0[a] (51.2) | 40.0 | 29.0[a] (27.5) | 22.0[a] (45.0) | 21.4[a] (46.7) | 35.0 | 26.0[a] (25.7) | 17.0[a] (51.4) | 14.0[a] (60.0) |
| CO 6 | 44.0 | 42.0 (4.6) | 38.0[a] (13.6) | 32.0[a] (27.3) | 42.0 | 33.0[a] (21.4) | 29.0[a] (31.0) | 20.0[a] (52.4) | 38.0 | 29.0[a] (23.7) | 20.0[a] (47.4) | 16.0[a] (57.9) | 33.0 | 24.0[a] (27.3) | 15.0[a] (54.6) | 12.0[a] (63.6) |
| GAUT 001E | 42.0 | 40.0 (4.8) | 37.0[a] (11.9) | 32.0[a] (23.8) | 40.0 | 32.0[a] (20.0) | 27.0[a] (30.9) | 19.0[a] (52.5) | 36.0 | 29.0[a] (19.4) | 20.0[a] (44.4) | 15.0[a] (58.3) | 33.0 | 24.0[a] (27.3) | 14.0[a] (57.6) | 11.0[a] (66.7) |
| GT 100 | 46.0 | 43.0[a] (6.5) | 43.0[a] (6.5) | 35.0[a] (23.9) | 45.0 | 35.0[a] (22.2) | 32.0[a] (28.9) | 23.0[a] (48.9) | 41.0 | 31.0[a] (24.4) | 22.0[a] (46.3) | 17.0[a] (58.5) | 36.0 | 27.0[a] (25.0) | 18.0[a] (50.0) | 11.0[a] (69.4) |
| Pusa 84 | 44.0 | 42.0 (4.6) | 39.0[a] (11.4) | 34.0[a] (22.7) | 43.0 | 35.0[a] (18.6) | 31.0[a] (27.9) | 23.0[a] (46.5) | 38.0 | 31.0[a] (18.4) | 24.0[a] (36.8) | 18.0[a] (52.6) | 34.0 | 27.0[a] (20.6) | 19.0[a] (44.1) | 14.0[a] (58.8) |
| AL 15 | 48.0 | 45.0[a] (6.3) | 43.0[a] (10.4) | 38.0[a] (20.8) | 46.0 | 39.0[a] (15.2) | 35.0[a] (23.9) | 26.0[a] (43.5) | 43.0 | 34.0[a] (20.9) | 27.0[a] (37.2) | 23.0[a] (46.5) | 39.0 | 31.0[a] (20.5) | 22.0[a] (43.6) | 18.0[a] (53.9) |
| Pusa 855 | 44.0 | 42.0 (4.6) | 39.0[a] (11.4) | 34.0[a] (22.7) | 43.0 | 35.0[a] (18.6) | 31.0[a] (27.9) | 23.0[a] (46.5) | 38.0 | 31.0[a] (18.4) | 30.7[a] (19.3) | 18.0[a] (52.6) | 34.0 | 27.0[a] (20.6) | 19.0[a] (44.1) | 14.0[a] (58.8) |
| Pusa 33 | 45.0 | 43.0 (4.4) | 38.0[a] (15.6) | 29.7[a] (34.1) | 44.0 | 34.0[a] (22.7) | 30.0[a] (31.8) | 21.0[a] (52.3) | 39.0 | 29.0[a] (25.6) | 22.0[a] (43.6) | 17.0[a] (56.4) | 34.0 | 26.0[a] (23.5) | 18.0[a] (47.1) | 13.0[a] (61.8) |
| Paras | 44.0 | 42.0 (4.6) | 37.0[a] (15.9) | 32.0[a] (27.3) | 42.0 | 33.0[a] (21.4) | 30.0[a] (28.6) | 20.0[a] (52.4) | 38.0 | 29.0[a] (23.7) | 20.0[a] (47.4) | 15.0[a] (60.5) | 33.0 | 25.0[a] (24.2) | 15.0[a] (54.6) | 11.0[a] (66.7) |
| AKT 8811 | 48.0 | 46.0 (4.2) | 42.0[a] (12.5) | 39.0[a] (18.8) | 47.0 | 39.0[a] (17.0) | 34.0[a] (27.7) | 25.0[a] (46.8) | 45.0 | 34.0[a] (24.4) | 24.0[a] (46.7) | 22.7[a] (49.6) | 43.0 | 30.0[a] (30.2) | 20.0[a] (53.5) | 15.0[a] (65.1) |
| ICP 14722 | 62.0 | 59.0[a] (4.8) | 54.0[a] (12.9) | 48.0[a] (22.6) | 62.0 | 48.0[a] (22.6) | 43.0[a] (30.7) | 32.0[a] (48.4) | 62.0 | 43.0[a] (30.7) | 32.0[a] (48.4) | 26.0[a] (58.1) | 61.0 | 38.0[a] (37.7) | 27.0[a] (55.7) | 22.0[a] (63.9) |
| ICP 8859 | 60.0 | 58.0 (3.3) | 53.0[a] (11.7) | 48.0[a] (20.0) | 60.0 | 47.0[a] (21.7) | 42.0[a] (30.0) | 33.0[a] (45.0) | 60.0 | 43.0[a] (28.3) | 34.0[a] (43.3) | 27.0[a] (55.0) | 59.0 | 37.0[a] (37.3) | 27.7[a] (53.1) | 22.0[a] (62.7) |
| ICPL 89049 | 63.0 | 60.0[a] (4.8) | 55.0[a] (12.7) | 39.0[a] (38.1) | 63.0 | 50.0[a] (20.6) | 44.0[a] (30.2) | 33.0[a] (47.6) | 60.0 | 45.0[a] (25.0) | 34.0[a] (43.3) | 31.3[a] (47.8) | 62.0 | 39.0[a] (37.1) | 27.0[a] (56.5) | 23.0[a] (62.9) |
| DPPA 85-13 | 60.0 | 57.0[a] (5.0) | 53.0[a] (11.7) | 48.0[a] (20.0) | 60.0 | 47.0[a] (21.7) | 43.0[a] (28.3) | 33.0[a] (45.0) | 60.0 | 42.0[a] (30.0) | 32.0[a] (46.7) | 26.0[a] (56.7) | 59.0 | 38.0[a] (35.6) | 27.0[a] (54.2) | 21.0[a] (64.4) |
| ICPL 89048 | 59.0 | 57.0 (3.4) | 53.0[a] (10.2) | 48.0[a] (18.6) | 59.0 | 48.0[a] (18.6) | 42.0[a] (28.8) | 32.0[a] (45.8) | 58.0 | 43.0[a] (25.9) | 32.0[a] (44.8) | 26.0[a] (55.2) | 58.0 | 37.0[a] (36.2) | 27.0[a] (53.5) | 21.0[a] (63.8) |
| ICPL 87119 | 62.0 | 59.0[a] (4.8) | 55.0[a] (11.3) | 50.0[a] (19.4) | 62.0 | 51.0[a] (17.7) | 46.0[a] (25.8) | 36.0[a] (41.9) | 60.0 | 45.0[a] (25.0) | 35.0[a] (41.7) | 29.0[a] (51.7) | 60.0 | 41.0[a] (31.7) | 30.0[a] (50.0) | 23.0[a] (61.7) |
| AWR 74/15 | 63.0 | 59.0[a] (6.4) | 55.0[a] (12.7) | 50.0[a] (20.6) | 60.0 | 51.0[a] (15.0) | 46.0[a] (23.3) | 37.0[a] (38.3) | 60.0 | 46.0[a] (23.3) | 36.0[a] (40.0) | 32.0[a] (46.7) | 60.0 | 41.0[a] (31.7) | 31.0[a] (48.3) | 27.0[a] (55.0) |
| ICP 8863 | 63.0 | 59.0[a] (6.4) | 57.0[a] (9.5) | 53.0[a] (15.9) | 63.0 | 52.0[a] (17.5) | 47.0[a] (25.4) | 39.0[a] (38.1) | 63.0 | 48.0[a] (23.8) | 38.0[a] (39.7) | 33.0[a] (47.6) | 63.0 | 43.0[a] (31.8) | 34.0[a] (46.0) | 29.0[a] (54.0) |
| Bahar | 65.0 | 62.0[a] (4.6) | 57.0[a] (12.3) | 52.0[a] (20.0) | 61.0 | (44.0)[a] (27.9) | (40.0)[a] (34.4) | 34.0[a] (44.3) | 56.0 | (40.0)[a] (28.5) | 34.0[a] (39.3) | 28.0[a] (50.0) | 50.0 | (35.0)[a] (30.0) | 29.0[a] (42.0) | 22.0[a] (56.0) |
| GCP 33 | 61.0 | 59.0 (3.3) | 55.0[a] (9.8) | 50.0[a] (18.0) | 61.0 | 51.0[a] (16.4) | 46.0[a] (24.6) | 35.0[a] (42.6) | 60.0 | 46.0[a] (23.3) | 29.0[a] (51.7) | 29.0[a] (51.7) | 59.0 | 41.0[a] (30.5) | 29.0[a] (50.9) | 24.0[a] (59.3) |

CD $P \leq 0.05$ : 2.5
$P \leq 0.01$ : 4.8

*F*- value

Fungus (df = 3) : $890.1^{cd}$
Nematode (df = 3) : $1336.9^{cd}$
Cultivar (df = 24) : $139.8^{cd}$
Fungus x Nematode (df = 9) : $47.0^{cd}$
Fungus x Cultivar (df = 9) : $2.2^{cd}$
Nematode x Cultivar (df = 9) : NS
Fungus x Nematode x Cultivars (df = 216) : NS

Figures in parenthesis are percent decrease over $0J_2$ of *M. incognita*; Significantly different from control at $P \leq 0.05$; [a]Significant different from control at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

Table 7. Effect of inoculations with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on functional root nodules in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | 38.0 | 34.0 (10.5) | 29.0 (23.7) | 24.0 (36.8) | 35.0 | 27.0 (30.8) | 21.0 (40.0) | 13.0 (62.9) | 30.0 | 20.0 (33.3) | 12.0 (60.0) | 10.0 (66.7) | 25.0 | 16.0 (34.0) | 10.0 (60.0) | 6.0 (76.0) |
| Manak | 42.0 | 38.0 (9.5) | 34.0 (19.0) | 29.0 (30.9) | 39.0 | 29.0 ((23.7) | 23.0 (41.0) | 14.0 (64.1) | 35.0 | 24.0 (31.4) | 14.0 (60.0) | 11.0 (68.6) | 29.0 | 19.0 (34.5) | 11.0 (62.1) | 7.0 (75.9) |
| AL 201 | 41.0 | 37.0 (9.8) | 21.0 (24.4) | 26.0 (36.6) | 38.0 | 26.0 (31.6) | 21.0 (44.7) | 12.0 (68.4) | 32.0 | 21.0 (34.4) | 12.0 (62.5) | 9.0 (71.9) | 27.0 | 16.0 (40.7) | 9.0 (66.7) | 6.0 (77.8) |
| C 11 | 41.0 | 38.0 (7.3) | 32.0 (21.9) | 26.0 (36.6) | 38.0 | 26.0 (36.6) | 21.0 (44.7) | 12.0 68.4) | 32.0 | 21.0 (34.4) | 11.0 (65.6) | 8.0 (75.0) | 27.0 | 16.0 (40.4) | 8.0 (70.4) | 5.0 (81.5) |
| Sarvodaya | 43.0 | 41.0 (4.6) | 36.0 (16.3) | 30.0 (30.2) | 41.0 | 30.0 (21.0) | 25.0 (39.0) | 17.0 (58.5) | 36.0 | 25.0 (30.1) | 17.0 (52.8) | 11.0 (69.4) | 30.0 | 21.0 (30.0) | 12.0 (60.0) | 8.0 (73.3) |
| ICPL 87 | 41.0 | 37.0 (9.8) | 32.0 (21.9) | 27.0 (34.1) | 38.0 | 28.0 (26.3) | 22.0 (42.1) | 13.0 (65.8) | 32.0 | 22.0 (31.2) | 14.0 (56.2) | 10.0 (68.7) | 27.0 | 18.0 (33.3) | 10.0 (63.0) | 7.0 (74.1) |
| CO 6 | 40.0 | 37.0 (7.5) | 31.0 (22.5) | 25.0 (37.5) | 38.0 | 27.0 (22.9) | 21.0 (44.7) | 12.0 (68.4) | 30.0 | 22.0 (26.7) | 12.0 (60.0) | 8.0 (73.3) | 27.0 | 16.0 (40.7) | 8.0 (70.4) | 5.0 (81.5) |
| GAUT 001E | 38.0 | 35.0 (7.9) | 30.0 (2.1) | 25.0 (34.2) | 35.0 | 25.0 (35.9) | 20.0 (42.9) | 12.0 (65.7) | 30.0 | 21.0 (30.0) | 12.0 (60.0) | 8.0 (73.3) | 26.0 | 16.0 (38.5) | 8.0 (69.2) | 5.0 (80.8) |
| GT 100 | 40.0 | 36.0 (10.0) | 32.0 (20.0) | 27.0 (32.5) | 39.0 | 27.0 (28.9) | 23.0 (41.0) | 15.0 (61.0) | 34.0 | 23.0 (32.3) | 14.0 (58.8) | 10.0 (70.6) | 28.0 | 18.0 (35.7) | 11.0 (60.7) | 6.0 (78.6) |
| Pusa 84 | 40.0 | 37.0 (7.5) | 33.0 (17.5) | 27.0 (32.5) | 38.0 | 27.0 (32.5) | 23.0 (39.5) | 15.0 (60.5) | 32.0 | 23.0 (28.1) | 15.0 (53.1) | 11.0 (65.6) | 27.0 | 19.0 (29.6) | 11.0 (59.3) | 8.0 (70.4) |
| AL 15 | 43.0 | 40.0 (7.0) | 36.0 (16.3) | 30.0 (30.2) | 40.0 | 31.0 (11.4) | 26.0 (35.0) | 17.0 (57.5) | 36.0 | 26.0 (27.8) | 17.0 (52.8) | 13.0 (63.9) | 32.0 | 21.0 (34.4) | 13.0 (59.4) | 9.0 (71.9) |
| Pusa 855 | 38.0 | 34.0 (10.5) | 28.0 (26.3) | 22.0 (42.1) | 35.0 | 23.0 (41.0) | 18.0 (48.5) | 10.0 (71.4) | 30.0 | 18.0 (40.0) | 9.0 (70.0) | 6.0 (80.0) | 24.0 | 13.0 (45.8) | 6.0 (75.0) | 4.0 (83.3) |
| Pusa 33 | 40.0 | 38.0 (5.0) | 32.0 (20.0) | 27.0 (32.5) | 39.0 | 27.0 (27.0) | 22.0 (43.6) | 14.0 (64.1) | 33.0 | 24.0 (27.2) | 15.0 (54.5) | 10.0 (69.7) | 27.0 | 19.0 (29.6) | 11.0 (59.3) | 7.0 (74.1) |
| Paras | 40.0 | 37.0 (7.5) | 31.0 (22.5) | 26.0 (35.0) | 37.0 | 26.0 (39.5) | 22.0 (40.5) | 13.0 (64.9) | 32.0 | 22.0 (31.2) | 13.0 (59.4) | 9.0 (71.9) | 26.0 | 17.0 (34.6) | 9.0 (65.4) | 6.0 (76.9) |
| AKT 8811 | 44.0 | 42.0 (4.5) | 36.0 (18.2) | 32.0 (27.3) | 43.0 | 33.0 (41.1) | 28.0 (34.9) | 18.0 (58.1) | 40.0 | 28.0 (30.0) | 17.0 (57.5) | 13.0 (67.5) | 36.0 | 23.0 (36.1) | 13.0 (63.9) | 9.0 (75.0) |
| ICP 14722 | 56.0 | 51.0 (8.9) | 44.0 (21.4) | 37.0 (33.9) | 56.0 | 37.0 (31.5) | 32.0 (42.9) | 19.0 (66.1) | 55.0 | 31.0 (43.6) | 19.0 (65.4) | 15.0 (72.7) | 54.0 | 26.0 (51.8) | 15.0 (72.2) | 12.0 (77.8) |
| ICP 8859 | 54.0 | 50.0 (7.4) | 44.0 (18.5) | 37.0 (31.5) | 54.0 | 37.0 (35.1) | 32.0 (40.7) | 21.0 (61.1) | 54.0 | 32.0 (40.7) | 21.0 (61.1) | 16.0 (70.3) | 52.0 | 26.0 (50.0) | 16.0 (69.2) | 12.0 (76.9) |
| ICPL 89049 | 57.0 | 52.0 (8.8) | 46.0 (19.3) | 39.0 (31.6) | 57.0 | 39.0 (27.8) | 32.0 (43.9) | 21.0 (63.2) | 56.0 | 33.0 (41.1) | 21.0 (62.5) | 16.0 (71.4) | 56.0 | 27.0 (51.8) | 16.0 (71.4) | 12.0 (78.6) |
| DPPA 85-13 | 54.0 | 50.0 (7.4) | 45.0 (16.7) | 38.0 (29.6) | 54.0 | 37.0 (27.4) | 31.0 (42.6) | 21.0 (61.1) | 54.0 | 31.0 (42.6) | 21.0 (61.1) | 16.0 (70.4) | 52.0 | 26.0 (50.0) | 17.0 (67.0) | 12.0 (76.9) |
| ICPL 89048 | 51.0 | 49.0 (3.9) | 44.0 (13.7) | 37.0 (27.4) | 51.0 | 36.0 (32.1) | 30.0 (41.2) | 20.0 (60.8) | 51.0 | 31.0 (39.2) | 20.0 (60.8) | 15.0 (70.6) | 51.0 | 25.0 (51.0) | 16.0 (68.6) | 11.0 (78.4) |
| ICPL 87119 | 53.0 | 49.0 (7.5) | 42.0 (20.7) | 37.0 (30.2) | 53.0 | 38.0 (30.9) | 33.0 (37.7) | 23.0 (56.6) | 51.0 | 32.0 (37.2) | 23.0 (54.9) | 18.0 (64.7) | 51.0 | 28.0 (45.1) | 18.0 (64.7) | 13.0 (74.5) |
| AWR 74/15 | 55.0 | 53.0 (3.6) | 46.0 (16.4) | 40.0 (27.3) | 55.0 | 41.0 (28.1) | 35.0 (36.4) | 25.0 (54.5) | 55.0 | 35.0 (36.4) | 24.0 (60.0) | 20.0 (66.7) | 55.0 | 30.0 (45.4) | 19.0 (65.4) | 15.0 (72.7) |
| ICP 8863 | 57.0 | 51.0 (10.5) | 49.0 (14.0) | 43.0 (24.6) | 57.0 | 42.0 (20.7) | 37.0 (35.1) | 26.0 (54.4) | 57.0 | 37.0 (35.1) | 26.0 (58.7) | 20.0 (68.2) | 57.0 | 31.0 (45.6) | 21.0 (63.2) | 17.0 (70.2) |
| Bahar | 59.0 | 54.0 (8.4) | 47.0 (20.3) | 41.0 (30.5) | 53.0 | 39.0 (29.1) | 30.0 (43.4) | 19.0 (64.1) | 47.0 | 31.0 (34.0) | 18.0 (67.9) | 14.0 (75.0) | 38.0 | 24.0 (36.8) | 14.0 (63.2) | 10.0 (73.7) |
| GCP 33 | 55.0 | 51.0 (7.3) | 45.0 (18.2) | 39.0 (29.1) | 55.0 | 40.0 (27.2) | 34.0 (38.2) | 22.0 (60.0) | 54.0 | 34.0 (37.0) | 22.0 (63.3) | 17.0 (71.7) | 53.0 | 28.0 (47.2) | 17.0 (67.9) | 13.0 (75.5) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 5.2 |
| CD $P \leq 0.01$ | : : 7.1 |
| *F*- value | |
| Fungus (df = 3) | :1955.8[ca] |
| Nematode (df = 3) | :3197.0[ca] |
| Cultivar (df = 24) | :174.6[ca] |
| Fungus x Nematode (df = 9) | :83.77[ca] |
| Fungus x Cultivar (df = 9) | : 6.91[ca] |
| Nematode x Cultivar (df = 9) | : NS |
| Fungus x Nematode x Cultivars (df = 216) | : NS |

Figures in parenthesis are percent decrease over $0J_2$ of M. incognita; Significantly different from control at $P \leq 0.05$a Significant at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [a]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

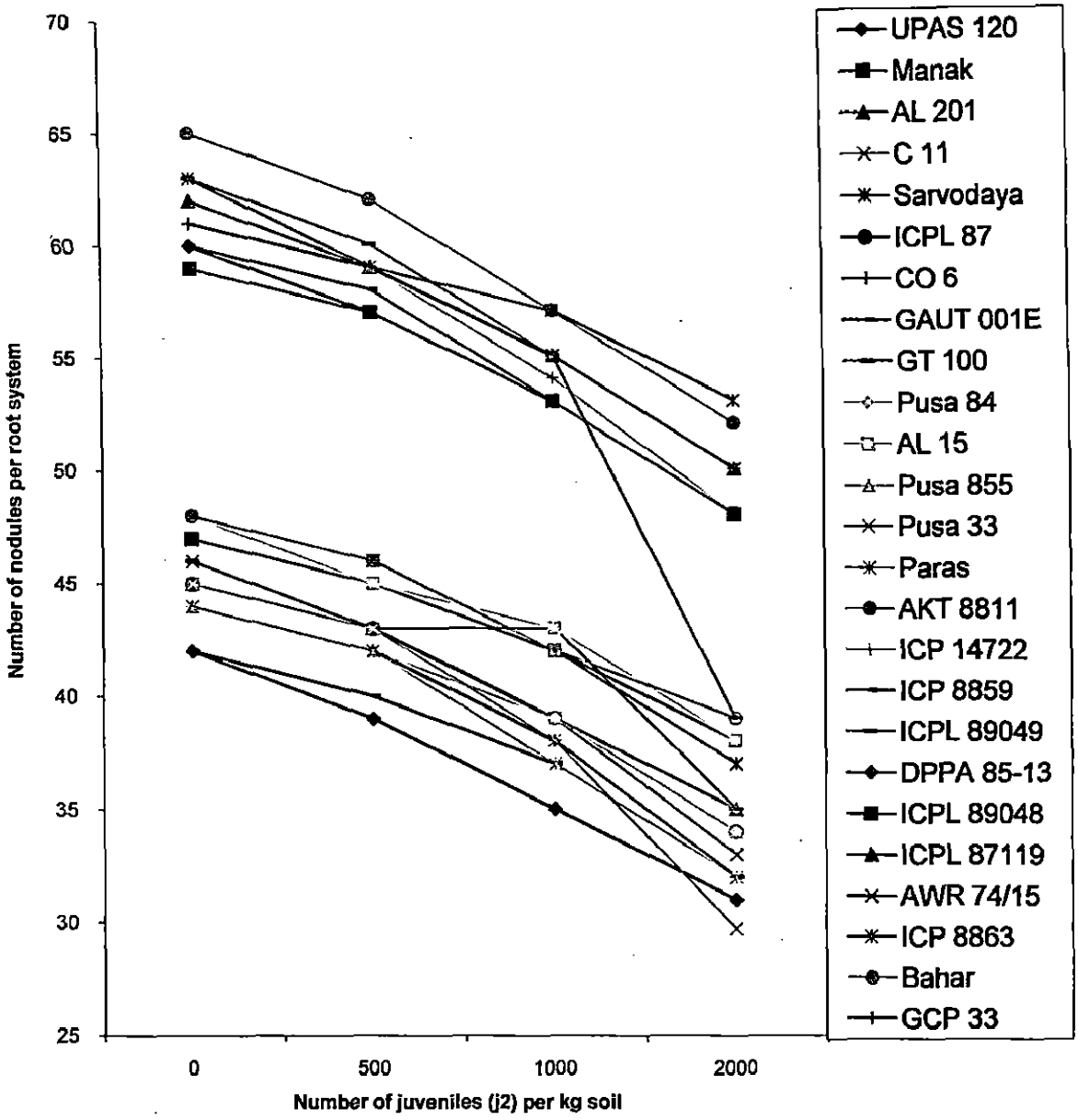


**Fig.8 Effect of inoculation with *Meloidogyne incognita* on the nodulation in pigeonpea under pot condition.**

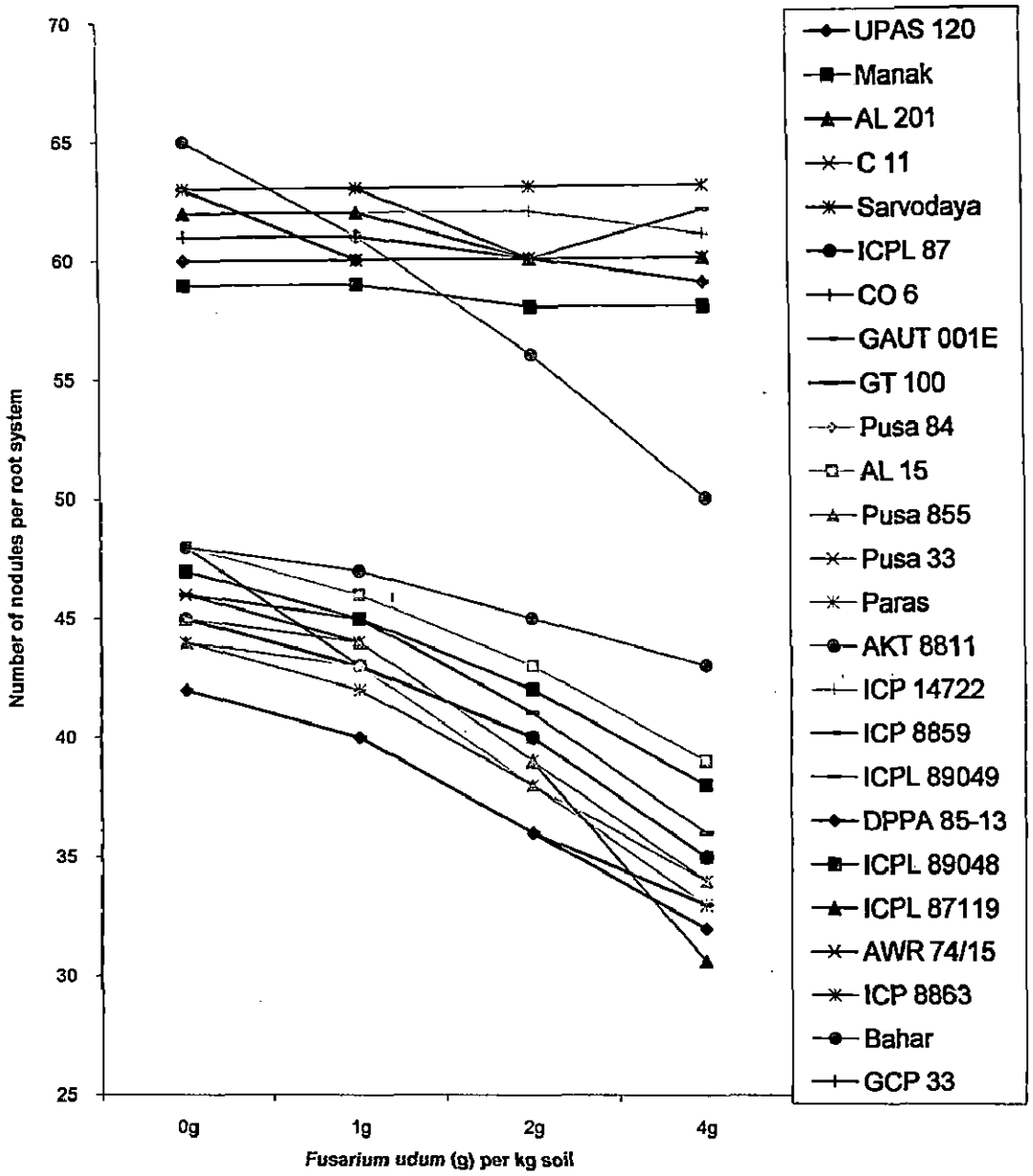


**Fig.9 Effect of inoculation with Fusarium udum on the nodulation in pigeonpea under pot condition.**

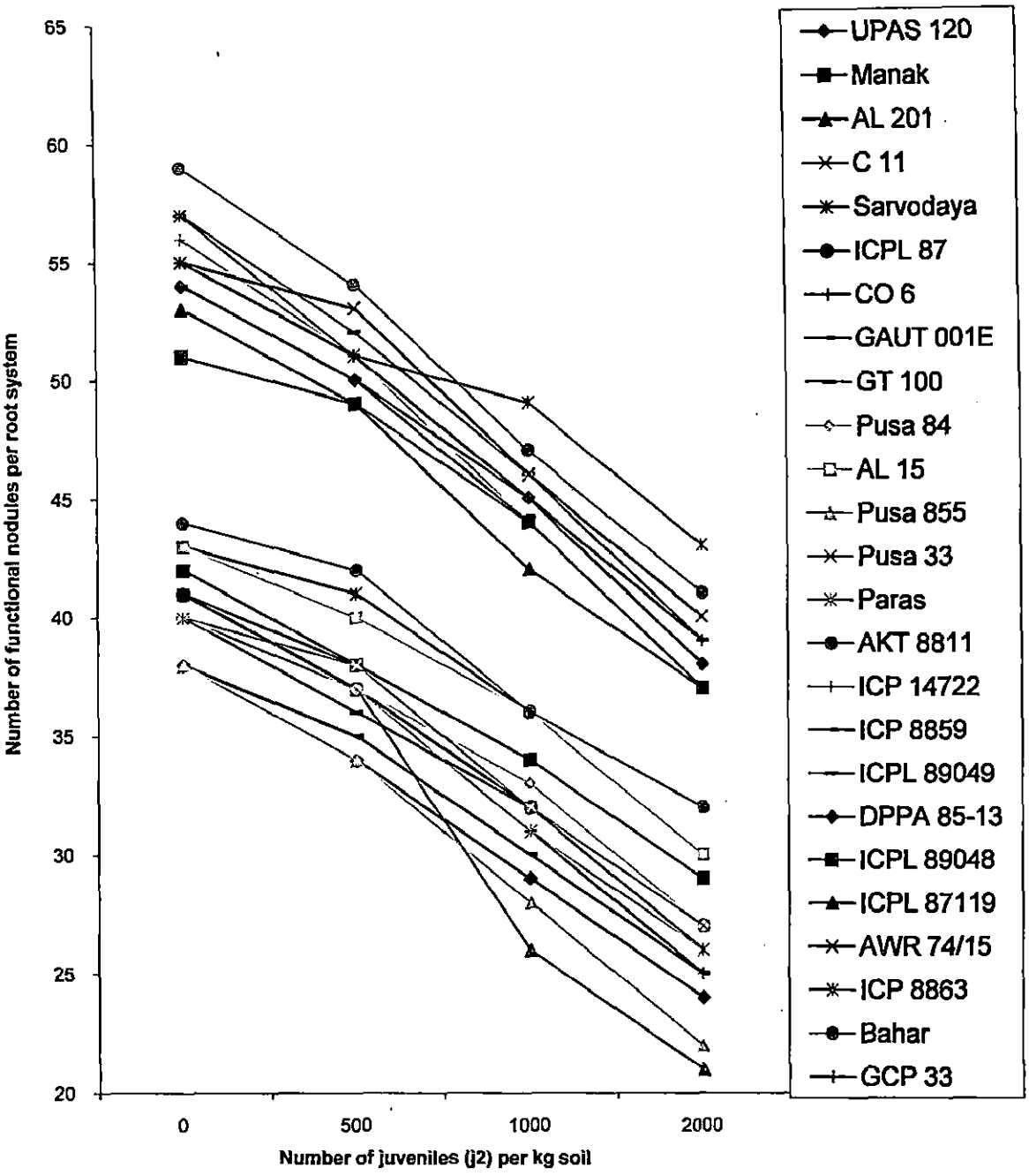


**Fig.10 Effect of inoculation with *Meloidogyne incognita* on functional root nodules in pigeonpea under pot condition.**

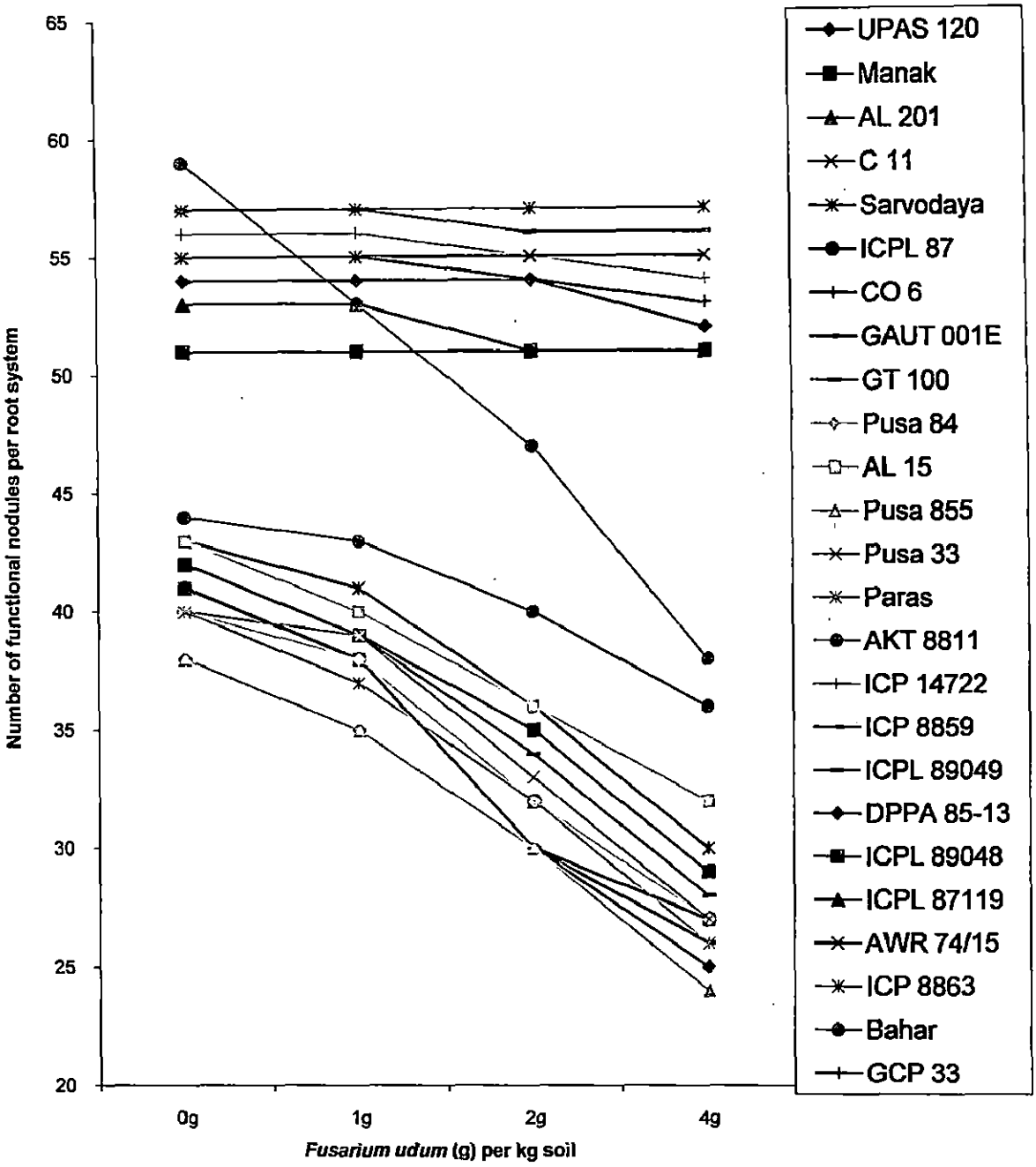


**Fig.11 Effect of inoculation with *Fusarium udum* on functional root nodules in pigeonpea under pot condition.**

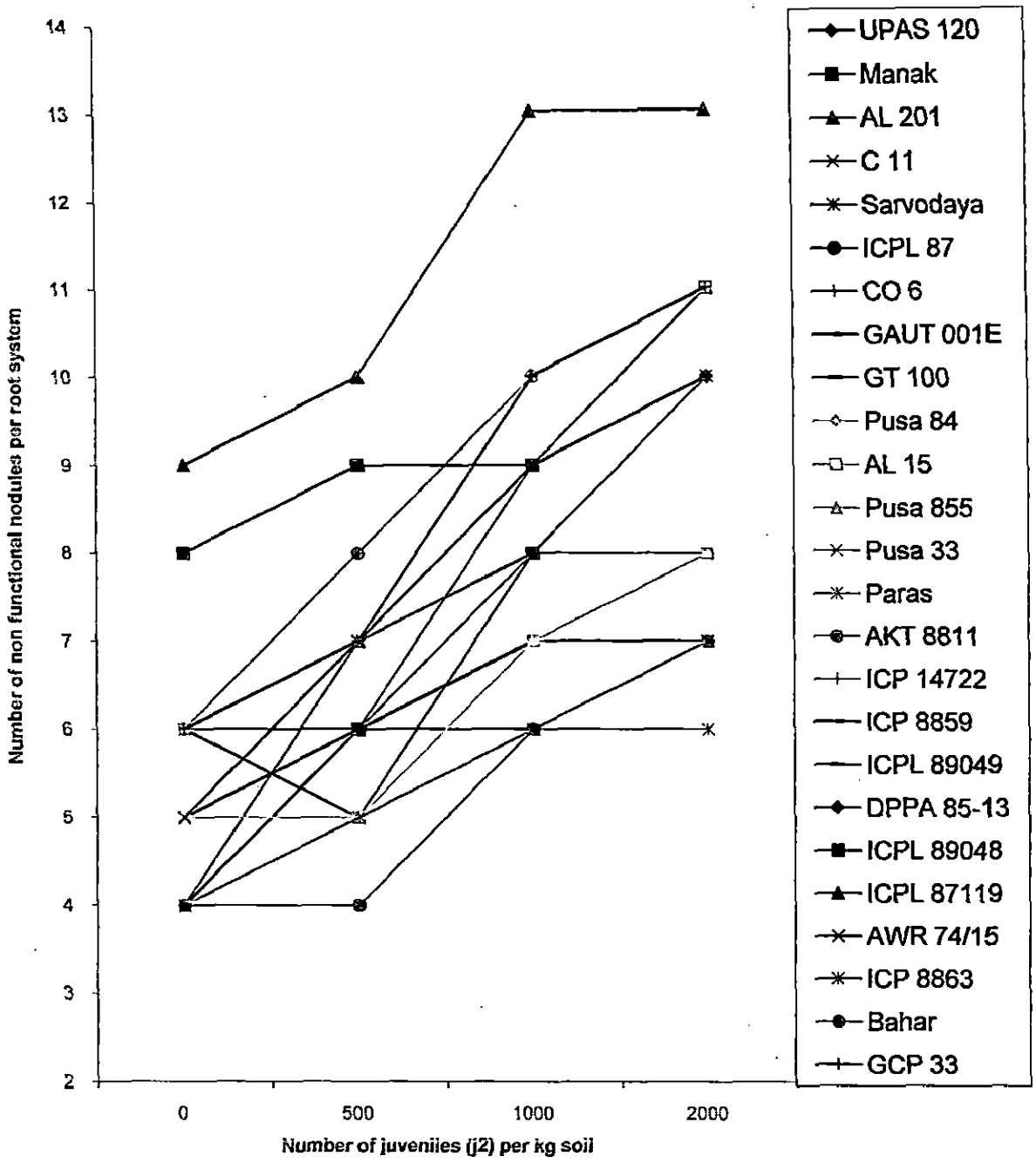


**Fig.12 Effect of inoculation with *Meloidogyne incognita on nonfunctional* root nodules in pigeonpea under pot condition.**

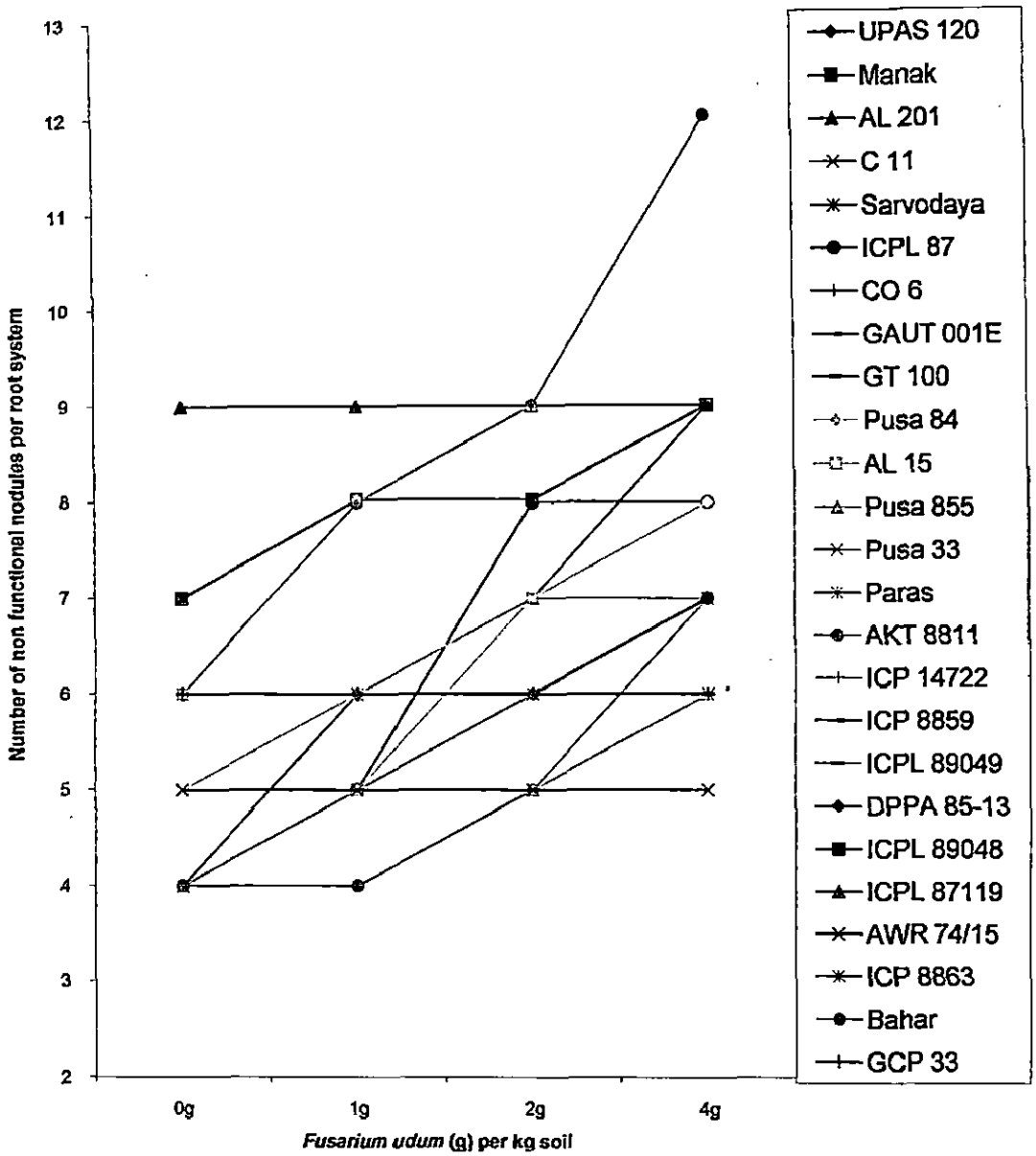


**Fig.13 Effect of inoculation with *Fusarium udum on non*functional root nodules in pigeonpea under pot condition.**

cvs. AWR 74/15 and ICP 8863 showed 140% and 100% increase in non-functional nodule at this combination (4g *F. udum* and 2000 $J_2$ of *M. incognita*) (Table 8).

### 4.2.5 Soil population of pathogens

Final population of juveniles of *M. incognita* in soil decreased in all the cultivars of pigeonpea at all the three initial inoculum levels i.e. 500, 1000 and 2000. However, percent increase in juveniles of *M. incognita* was highest at 500 followed by 1000 and 2000 (Table 9, Fig 14). At 500, 1000 and 2000 initial inoculum level of *M. incognita*, maximum increase was observed in CO6 which was 187, 84 and 57% respectively.
The least increase in soil population juveniles at 500 initial inoculum level of *M. incognita* was observed in AKT 8811 (125%) whereas at 1000 and 2000 level of *M. incognita* it was 54.5 and 23.5%, respectively in cv. ICP 8863.

*F. udum* when applied in combination with *M. incognita* shows a suppressive effect on the $J_2$ population of *M. incognita*. The final population of nematode increased 158% (cv. C06) when 500 $J_2$ was combined with 1 g wilt fungus *F. udum* (Table 9). When the inoculum level of fungus was increased to 2 g the increase in $J_2$ population in soil was 137% whereas at 4 g it was 105.4%. In cv. Bahar the population increased the highest in Bahar (99, 82 and 64%) in case of 1, 2 and 4 g fungus respectively concomitantly with 500 $J_2$. At 4 g wilt fungus and 2000 $J_2$ population of *M. incognita* there was a slight increase (11.7%) in the population of soil nematode as compared with the initial inoculum level (Table 9).

The soil population of *F. udum* gradually increased during the cropping season. The peak population was observed during the mid season of crop $6x10^{16}$ CFUs/g at 4 g wilt fungus combined with 2000 $J_2$ of *M. incognita* (Table 10-18). Increase was lowest ($1.38x10^{16}$ CFUs/g) soil at the combination of 1g fungus with 500 $J_2$ of *M. incognita*. The mid season population in case of fungus alone was $4x10^{16}$ whereas final population was $1x10^{16}$. The final population of fungus was lowest in ICP 8863 which was $6.44x10^{15}$ CFUs/g (Table 10). At harvest the population of *F. udum* decreased in soil however, it was more than the initial inoculum level.

Table 8. Effect of inoculations with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on non functional root nodules in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | 4.0 | 5.0 (25.0) | 6.0 (50.0) | 7.0 (75.0) | 5.0 | 7.0 (40.0) | 8.0 (60.0) | 8.0 (60.0) | 6.0 | 7.0 (16.7) | 9.0 (50.0) | 6.0 0.0 | 7.0 | 8.0 (14.3) | 6.0 (-14.3) | 5.0 (-28.6) |
| Manak | 5.0 | 6.0 (26.6) | 8.0 (60.0) | 8.0 (60.0) | 6.0 | 8.0 (33.3) | 9.0 (50.0) | 10.0 (66.7) | 7.0 | 9.0 (28.6) | 9.0 (28.6) | 8.0 (14.3) | 9.0 | 9.0 0.0 | 9.0 0.0 | 7.0 (-22.2) |
| AL 201 | 4.0 | 7.0 (75.0) | 8.0 (100.0) | 8.0 (100.0) | 6.0 | 8.0 (33.3) | 9.0 (50.0) | 9.0 (50.0) | 7.0 | 8.0 (14.3) | 9.0 (28.6) | 8.0 (14.3) | 7.0 | 9.0 (28.6) | 8.0 (14.3) | 7.0 0.0 |
| C 11 | 5.0 | 5.0 (6.6) | 7.0 (40.0) | 7.0 (40.0) | 6.0 | 7.0 (16.7) | 7.0 (16.7) | 7.0 (16.7) | 7.0 | 7.0 0.0 | 7.0 0.0 | 6.0 (-14.3) | 7.0 | 7.0 0.0 | 6.0 (-14.3) | 5.0 (-28.5) |
| Sarvodaya | 5.0 | 6.0 (33.4) | 6.0 (20.0) | 7.0 (40.0) | 2.0 | 7.0 (16.7) | 8.0 (33.3) | 8.0 (33.3) | 4.0 | 8.0 (14.3) | 7.0 0.0 | 7.0 0.0 | 5.0 | 8.0 0.0 | 6.0 (-12.5) | 6.0 (-25.0) |
| ICPL 87 | 4.0 | 6.0 (58.2) | 7.0 (75.0) | 7.0 (75.0) | 5.0 | 6.0 (20.0) | 8.0 (60.0) | 8.0 (60.0) | 8.0 | 7.0 (-12.5) | 8.0 0.0 | 8.0 0.0 | 8.0 | 8.0 0.0 | 7.0 (-12.5) | 7.0 (-12.5) |
| CO 6 | 4.0 | 5.0 (33.2) | 7.0 (75.0) | 7.0 (75.0) | 5.0 | 6.0 (20.0) | 8.0 (60.0) | 8.0 (60.0) | 8.0 | 7.0 (-12.5) | 8.0 0.0 | 8.0 0.0 | 6.0 | 8.0 (33.3) | 7.0 (16.7) | 7.0 (16.7) |
| GAUT 001E | 4.0 | 5.0 (25.0) | 7.0 (75.0) | 7.0 (75.0) | 5.0 | 7.0 (40.0) | 8.0 (60.0) | 7.0 (40.0) | 6.0 | 8.0 (33.3) | 8.0 (33.3) | 7.0 (16.7) | 7.0 | 8.0 (14.3) | 6.0 (-14.3) | 6.0 (-14.3) |
| GT 100 | 6.0 | 5.0 (-16.7) | 8.0 (33.3) | 8.0 (33.3) | 6.0 | 8.0 (33.3) | 9.0 (50.0) | 8.0 (33.3) | 7.0 | 8.0 (14.3) | 8.0 (14.3) | 7.0 0.0 | 7.0 | 8.0 (24.9) | 7.0 (4.9) | 5.0 (-25.0) |
| Pusa 84 | 4.0 | 5.0 (25.0) | 6.0 (50.0) | 7.0 (75.0) | 5.0 | 8.0 (60.0) | 8.0 (60.0) | 8.0 (60.0) | 8.0 | 8.0 0.0 | 9.0 (12.5) | 7.0 (-12.5) | 7.0 | 8.0 (14.3) | 8.0 (14.3) | 6.0 (-14.3) |
| AL 15 | 5.0 | 5.0 (6.6) | 7.0 (40.0) | 8.0 (60.0) | 6.0 | 8.0 (33.3) | 9.0 (50.0) | 9.0 (50.0) | 7.0 | 8.0 (14.3) | 10.0 (42.9) | 10.0 (42.9) | 7.0 | 10.0 (42.9) | 9.0 (28.6) | 9.0 (28.6) |
| Pusa 855 | 4.0 | 5.0 (25.0) | 6.0 (50.0) | 7.0 (75.0) | 5.0 | 7.0 (40.0) | 8.0 (60.0) | 7.0 (40.0) | 5.0 | 7.0 (40.0) | 7.0 (40.0) | 6.0 (20.0) | 6.0 | 8.0 (33.3) | 6.0 0.0 | 5.0 (-16.7) |
| Pusa 33 | 4.0 | 5.0 (33.2) | 6.0 (50.0) | 6.0 (50.0) | 5.0 | 7.0 (40.0) | 8.0 (60.0) | 7.0 (40.0) | 6.0 | 7.0 (16.7) | 7.0 (16.7) | 7.0 (16.7) | 7.0 | 7.0 0.0 | 7.0 0.0 | 6.0 (-14.3) |
| Paras | 4.0 | 5.0 (250 | 6.0 (50.0) | 6.0 (50.0) | 5.0 | 7.0 (40.0) | 8.0 (60.0) | 7.0 (40.0) | 6.0 | 7.0 (16.7) | 7.0 (16.7) | 6.0 0.0 | 7.0 | 8.0 (-14.3) | 6.0 (-14.3) | 5.0 (-28.6) |
| AKT 8811 | 4.0 | 4.0 0.0 | 6.0 (50.0) | 7.0 (75.0) | 4.0 | 6.0 (50.0) | 6.0 (50.0) | 7.0 (75.0) | 5.0 | 6.0 (20.0) | 7.0 (40.0) | 7.0 (40.0) | 7.0 | 7.0 0.0 | 7.0 0.0 | 6.0 (-14.3) |
| ICP 14722 | 6.0 | 8.0 (27.8) | 10.0 (66.7) | 11.0 (83.3) | 6.0 | 11.0 (83.3) | 11.0 (83.3) | 13.0 (116.7) | 7.0 | 12.0 (71.4) | 13.0 (85.7) | 11.0 (57.1) | 7.0 | 12.0 (71.4) | 12.0 (71.4) | 10.0 (42.9) |
| ICP 8859 | 6.0 | 6.0 0.0 | 9.0 (50.0) | 11.0 (83.3) | 6.0 | 10.0 (66.7) | 10.0 (66.7) | 12.0 (100.0) | 6.0 | 11.0 (83.3) | 13.0 (116.7) | 11.0 (83.3) | 7.0 | 11.0 (57.1) | 12.0 (71.4) | 10.0 (42.9) |
| ICPL 89049 | 6.0 | 6.0 (5.5) | 9.0 (50.0) | 10.0 (66.7) | 6.0 | 11.0 (83.3) | 12.0 (100.0) | 12.0 (100.0) | 6.0 | 12.0 (100.0) | 13.0 (116.7) | 12.0 (100.0) | 6.0 | 12.0 (100.0) | 12.0 (100.0) | 11.0 (83.3) |
| DPPA 85-13 | 6.0 | 6.0 (5.5) | 8.0 (33.3) | 10.0 (66.7) | 6.0 | 10.0 (66.7) | 12.0 (100.0) | 12.0 (100.0) | 6.0 | 11.0 (83.3) | 11.0 (83.3) | 10.0 (66.7) | 7.0 | 12.0 (71.4) | 10.0 (42.9) | 9.0 (28.6) |
| ICPL 89048 | 8.0 | 9.0 (8.4) | 9.0 (12.5) | 11.0 (37.5) | 7.0 | 12.0 (71.4) | 12.0 (71.4) | 12.0 (71.4) | 7.0 | 12.0 (71.4) | 12.0 (71.4) | 11.0 (57.1) | 7.0 | 12.0 (71.4) | 11.0 (57.1) | 10.0 (42.9) |
| ICPL 87119 | 9.0 | 10.0 (7.4) | 13.0 (44.4) | 13.0 (44.4) | 9.0 | 13.0 (44.4) | 13.0 (44.4) | 13.0 (44.4) | 9.0 | 13.0 (44.4) | 12.0 (33.3) | 11.0 (22.2) | 9.0 | 13.0 (44.4) | 12.0 (33.3) | 10.0 (11.1) |
| AWR 74/15 | 5.0 | 7.0 (33.4) | 9.0 (80.0) | 10.0 (100.0) | 5.0 | 10.0 (100.0) | 11.0 (120.0) | 12.0 (140.0) | 5.0 | 11.0 (120.0) | 12.0 (140.0) | 12.0 (140.0) | 5.0 | 12.0 (140.0) | 12.0 (140.0) | 12.0 (140.0) |
| ICP 8863 | 6.0 | 6.0 0.0 | 8.0 (33.3) | 10.0 (66.7) | 6.0 | 10.0 (66.7) | 10.0 (66.7) | 13.0 (116.7) | 6.0 | 11.0 (83.3) | 12.0 (100.0) | 13.0 (116.7) | 6.0 | 12.0 (100.0) | 13.0 (116.7) | 12.0 (100.0) |
| Bahar | 6.0 | 8.0 (38.8) | 10.0 (66.7) | 11.0 (83.3) | 8.0 | 11.0 (37.5) | 13.0 (62.5) | 15.0 (87.5) | 9.0 | 13.0 (44.4) | 16.0 (77.8) | 14.0 (55.6) | 12.0 | 14.0 (16.7) | 15.0 (25.0) | 12.0 0.0 |
| GCP 33 | 6.0 | 7.0 (22.2) | 10.0 (66.7) | 11.0 (83.3) | 6.0 | 11.0 (77.8) | 12.0 (100.0) | 13.0 (116.7) | 6.0 | 12.0 (100.0) | 12.0 (100.0) | 12.0 (100.0) | 6.0 | 13.0 (116.7) | 12.0 (100.0) | 11.0 (83.3) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 3.3 |
| CD $P \leq 0.01$ | : 4.5 |
| F- value | |
| Fungus (df = 3) | : $43.5^{ca}$ |
| Nematode (df = 3) | : $118.6^{ca}$ |
| Cultivar (df = 24) | : $33.2^{ca}$ |
| Fungus x Nematode (df = 9) | : $11.9^{ca}$ |
| Fungus x Cultivar (df = 9) | : $2.3^{c}$ |
| Nematode x Cultivar (df = 9) | : NS |
| Fungus x Nematode x Cultivars (df = 216) | : NS |

Figures in parenthesis are percent decrease over control; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from co at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

Table 9. Effect of inoculations with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on soil population of nematodes in pigeonpea under pot culture condition

| Cultivar | Inoculation with *Fusarium udum* (fungus colonized seeds/kg soil) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0g | | | | 1g | | | | 2g | | | | 4g | | | |
| | Inoculation with *Meloidogyne incognita* (juveniles/kg soil) | | | | | | | | | | | | | | | |
| | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 | 0 | 500 | 1000 | 2000 |
| UPAS 120 | | 1310 (162.0) | 1670 (67.0) | 2590 (29.5) | | 1240 (148.0) | 1422 (42.2) | 2555 (27.7) | | 1150 (130.0) | 1315 (31.5) | 2390 (19.5) | | 950 (90.0) | 1245 (24.5) | 2342 (17.1) |
| Manak | | 1285 (157.0) | 1615 (61.5) | 2498 (25.0) | | 1073 (114.6) | 1372 (37.2) | 2485 (24.2) | | 980 (96.0) | 1210 (21.0) | 2364 (18.2) | | 893 (78.6) | 1187 (18.7) | 2293 (14.6) |
| AL 201 | | 1335 (167.0) | 1785 (78.5) | 2984 49.2) | | 1252 (150.4) | 1560 (56.0) | 2629 (31.4) | | 1146 (129.2) | 1424 (42.4) | 2542 (27.1) | | 996 (99.2) | 1390 (39.0) | 2463 (23.1) |
| C 11 | | 1335 (167.0) | 1760 (76.0) | 2935 (46.7) | | 1240 (148.0) | 1542 (54.2) | 2618 (30.9) | | 1135 (137.0) | 1410 (41.0) | 2526 (26.3) | | 991 (98.2) | 1390 (39.0) | 2445 (22.2) |
| Sarvodaya | | 1175 (135.0) | 1590 (59.0) | 2493 (24.6) | | 1069 (113.8) | 1372 (37.2) | 2475 (23.7) | | 975 (95.0) | 1278 (27.8) | 2355 (17.7) | | 897 (79.4) | 1180 (18.0) | 2290 (14.5) |
| ICPL 87 | | 1393 (178.0) | 1760 (76.0) | 2820 (41.0) | | 1225 (145.0) | 1532 (53.2) | 2610 (30.5) | | 1127 (125.4) | 1384 (38.4) | 2515 (25.7) | | 985 (97.0) | 1323 (32.3) | 2435 (21.7) |
| CO 6 | | 1435 (187.0) | 1840 (84.0) | 3140 (57.0) | | 1290 (158.0) | 1575 (57.5) | 2667 (33.3) | | 1185 (137.0) | 1463 (46.3) | 2590 (29.5) | | 1027 (105.4) | 1362 (36.2) | 2510 (25.5) |
| GAUT 001E | | 1348 (169.6) | 1788 (78.8) | 2990 (49.5) | | 1270 (154.0) | 1560 (56.0) | 2644 932.2) | | 1152 (130.4) | 1440 (44.0) | 2476 (23.8) | | 1013 (102.6) | 1410 (41.0) | 2450 (22.5) |
| GT 100 | | 1229 (145.8) | 1670 (67.0) | 2560 (28.0) | | 1138 (127.6) | 1410 (41.0) | 2540 (27.0) | | 1025 (105.0) | 1298 (29.8) | 2392 (19.6) | | 939 (87.8) | 1295 (29.5) | 2328 (16.4) |
| Pusa 84 | | 1197 (139.4) | 1625 (62.5) | 2510 (25.5) | | 1088 (117.6) | 1380 (38.0) | 2510 (25.5) | | 985 (97.0) | 1285 (28.5) | 2370 (18.5) | | 920 (84.0) | 1250 (25.0) | 2300 (15.0) |
| AL 15 | | 1310 (162.0) | 1748 (74.8) | 2810 (40.5) | | 1210 (142.0) | 1520 (52.0) | 2603 (30.2) | | 1090 (118.0) | 1391 (39.1) | 2497 (24.8) | | 1082 (116.4) | 1370 (37.0) | 2418 (20.9) |
| Pusa 855 | | 1362 (172.4) | 1822 (82.2) | 3050 (52.5) | | 1290 (158.0) | 1568 (56.8) | 2660 933) | | 1173 (134.6) | 1456 (45.6) | 2570 (28.5) | | 1019 (103.8) | 1422 (42.2) | 2490 (24.5) |
| Pusa 33 | | 1275 (155.0) | 1690 (69.0) | 2650 (32.5) | | 1173 (134.6) | 1475 (47.5) | 2573 (28.6) | | 1076 (115.2) | 1340 (34.0) | 2439 (21.9) | | 970 (94.0) | 1327 (32.7) | 2365 (18.2) |
| Paras | | 1282 (156.4) | 1690 (69.0) | 2695 (34.8) | | 1179 (135.8) | 1470 (47.0) | 2586 (29.3) | | 1085 (117.0) | 1355 (35.5) | 2465 (23.2) | | 970 (94.0) | 1327 (32.7) | 2380 (19.0) |
| AKT 8811 | | 1126 (125.2) | 1530 (53.0) | 2452 (22.6) | | 1010 (102.0) | 1346 (34.6) | 2420 (21.0) | | 922 (84.4) | 1250 (25.0) | 2325 (16.2) | | 840 (68.0) | 1145 914.5) | 2245 (12.2) |
| ICP 14722 | | 1265 (153.0) | 1680 (68.0) | 2620 (31.0) | | 1160 (132.0) | 1455 (45.5) | 2569 (28.4) | | 1058 (116.0) | 1327 (32.7) | 2430 (21.5) | | 973 (94.6) | 1320 (32.0) | 2353 (17.6) |
| ICP 8859 | | 1229 (145.8) | 1645 (64.5) | 2560 (28.0) | | 1120 (124.0) | 1398 (39.8) | 2528 (26.4) | | 1015 (103.0) | 1293 (29.3) | 2388 (19.4) | | 939 (87.8) | 1270 (27.0) | 2318 (15.9) |
| ICPL 89049 | | 1298 (159.6) | 1730 (73.0) | 2748 (37.4) | | 1198 (139.6) | 1495 (49.5) | 2590 (29.5) | | 1095 (119.0) | 1363 (36.3) | 2480 (24.0) | | 972 (94.4) | 1362 (36.2) | 2392 (19.6) |
| DPPA 85-13 | | 1159 (131.8) | 1590 (59.0) | 2480 (24.0) | | 1057 (111.0) | 1365 (36.5) | 2470 (23.5) | | 960 (92.0) | 1272 (27.2) | 2349 (17.5) | | 870 (74.0) | 1172 (17.2) | 2280 (14.0) |
| ICPL 89048 | | 1293 (158.6) | 1720 (72.0) | 2723 (36.2) | | 1190 (138.0) | 1484 (48.4) | 2590 (29.5) | | 1095 (119.0) | 1355 935.5) | 2480 (24.0) | | 978 (95.6) | 1345 (34.5) | 2383 (19.1) |
| ICPL 87119 | | 1220 (144.0) | 1625 (62.5) | 2535 (26.7) | | 1093 (119.0) | 1389 (38.9) | 2517 (25.8) | | 993 (98.6) | 1293 (29.3) | 2373 (18.6) | | 933 (86.6) | 1275 (27.5) | 2310 (15.5) |
| AWR 74/15 | | 1130 (126.0) | 1565 (56.5) | 2480 (24.0) | | 1040 (108.0) | 1357 (35.7) | 2455 (22.7) | | 960 (92.0) | 1272 (27.2) | 2340 (17.0) | | 875 (75.0) | 1163 (16.3) | 2280 (14.0) |
| ICP 8863 | | 1163 (132.0) | 1545 (54.5) | 2470 (23.5) | | 1025 (105.0) | 1355 (36.0) | 2440 (22.0) | | 940 (88.0) | 1267 (26.7) | 2340 (17.0) | | 852 (70.4) | 1138 (13.8) | 2263 (13.1) |
| Bahar | | 1120 (124.0) | 1795 (79.5) | 2830 (42.0) | | 995 (99.0) | 1422 (42.2) | 2432 (21.6) | | 910 (82.0) | 1327 932.7) | 2315 (15.7) | | 820 (64.0) | 1229 (22.9) | 2235 (11.7) |
| GCP 33 | | 1260 (152.0) | 1680 (68.0) | 2595 (30.0) | | 1160 (132.0) | 1430 (43.0) | 2563 (28.1) | | 1045 (109.0) | 1320 (32.0) | 2405 (20.2) | | 953 (90.6) | 1317 (31.7) | 2350 (17.5) |

| | |
|---|---|
| CD $P \leq 0.05$ | : 360.9 |
| CD $P \leq 0.01$ | : : 483.3 |
| *F* - value | |
| Fungus (df = 3) | : $35.8^{cd}$ |
| Nematode (df = 3) | : $13.8^{cd}$ |
| Cultivar (df = 24) | : $5.1^{cd}$ |
| Fungus x Nematode (df = 9) | : $1095.8^{cd}$ |
| Fungus x Cultivar (df = 9) | : NS |
| Nematode x Cultivar (df = 9) | : NS |
| Fungus x Nematode x Cultivars (df = 216) | : NS |

Figures in parenthesis are percent increase over respective 500, 1000 and 2000 level; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from control at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

Table 10. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (1g) and *Meloidogyne incognita* (500 $J_2$), singly and concomitantly in pigeonpea under field condition

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $1.40X10^4$ | $1.40X10^4$ | $1.53X10^5$ | $1.46X10^5$ | $1.32X10^4$ | $1.13X10^4$ |
| Manak | $1.40X10^4$ | $1.40X10^4$ | $1.58X10^5$ | $1.51X10^5$ | $1.37X10^4$ | $1.17X10^4$ |
| ICPL 87 | $1.40X10^4$ | $1.40X10^4$ | $1.75X10^5$ | $1.67X10^5$ | $1.51X10^4$ | $1.30X10^4$ |
| ICP 14722 | $1.40X10^4$ | $1.40X10^4$ | $6.03X10^4$ | $5.60X10^4$ | $1.47X10^4$ | $1.26X10^4$ |
| AL 201 | $1.40X10^4$ | $1.40X10^4$ | $1.74X10^5$ | $1.66X10^5$ | $1.50X10^4$ | $1.28X10^4$ |
| C11 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.65X10^5$ | $1.48X10^4$ | $1.27X10^4$ |
| Sarvodaya | $1.40X10^4$ | $1.40X10^4$ | $1.62X10^5$ | $1.55X10^5$ | $1.40X10^4$ | $1.19X10^4$ |
| ICP 8859 | $1.40X10^4$ | $1.40X10^4$ | $5.94X10^4$ | $5.43X10^4$ | $4.78X10^3$ | $3.88X10^3$ |
| ICPL 89049 | $1.40X10^4$ | $1.40X10^4$ | $5.40X10^4$ | $4.99X10^4$ | $4.32X10^3$ | $3.43X10^3$ |
| DPPA 85-13 | $1.40X10^4$ | $1.40X10^4$ | $5.58X10^4$ | $5.15X10^4$ | $4.48X10^3$ | $3.57X10^3$ |
| ICPL 89048 | $1.40X10^4$ | $1.40X10^4$ | $5.36X10^4$ | $4.90X10^4$ | $4.24X10^3$ | $3.36X10^3$ |
| ICPL 87119 | $1.40X10^4$ | $1.40X10^4$ | $5.67X10^4$ | $5.25X10^4$ | $4.59X10^3$ | $3.71X10^3$ |
| AKT 8811 | $1.40X10^4$ | $1.40X10^4$ | $1.52X10^5$ | $1.45X10^5$ | $1.30X10^4$ | $1.11X10^4$ |
| CO-6 | $1.40X10^4$ | $1.40X10^4$ | $1.74X10^5$ | $1.66X10^5$ | $1.50X10^4$ | $1.28X10^4$ |
| GAUT 001E | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.65X10^5$ | $1.49X10^4$ | $1.27X10^4$ |
| GT 100 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.67X10^5$ | $1.49X10^4$ | $1.28X10^4$ |
| Pusa 84 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.68X10^5$ | $1.52X10^4$ | $1.30X10^4$ |
| AWR 74/15 | $1.40X10^4$ | $1.40X10^4$ | $5.40X10^4$ | $4.90X10^4$ | $4.00X10^3$ | $3.15X10^3$ |
| ICP 8863 | $1.40X10^4$ | $1.40X10^4$ | $4.50X10^4$ | $4.03X10^4$ | $3.28X10^3$ | $2.58X10^3$ |
| AL 15 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.66X10^5$ | $1.50X10^4$ | $1.28X10^4$ |
| Pusa 855 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.67X10^5$ | $1.50X10^4$ | $1.29X10^4$ |
| Bahar | $1.40X10^4$ | $1.40X10^4$ | $1.80X10^5$ | $1.75X10^5$ | $1.60X10^4$ | $1.40X10^4$ |
| GCP 33 | $1.40X10^4$ | $1.40X10^4$ | $5.94X10^4$ | $5.43X10^4$ | $4.96X10^3$ | $3.99X10^3$ |
| Pusa 33 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.65X10^5$ | $1.50X10^4$ | $1.30X10^4$ |
| Paras | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.66X10^5$ | $1.52X10^4$ | $1.30X10^4$ |

Table 11. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (1g) and *Meloidogyne incognita* (1000 $J_2$), singly and concomitantly in pigeonpea under field condition

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $1.40X10^4$ | $1.40X10^4$ | $1.53X10^5$ | $1.67X10^5$ | $1.32X10^4$ | $1.22X10^4$ |
| Manak | $1.40X10^4$ | $1.40X10^4$ | $1.58X10^5$ | $1.73X10^5$ | $1.37X10^4$ | $1.25X10^4$ |
| ICPL 87 | $1.40X10^4$ | $1.40X10^4$ | $1.75X10^5$ | $1.91X10^5$ | $1.51X10^4$ | $1.39X10^4$ |
| ICP 14722 | $1.40X10^4$ | $1.40X10^4$ | $6.03X10^4$ | $6.40X10^4$ | $1.47X10^4$ | $1.35X10^4$ |
| AL 201 | $1.40X10^4$ | $1.40X10^4$ | $1.74X10^5$ | $1.90X10^5$ | $1.50X10^4$ | $1.37X10^4$ |
| C11 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.88X10^5$ | $1.48X10^4$ | $1.36X10^4$ |
| Sarvodaya | $1.40X10^4$ | $1.40X10^4$ | $1.62X10^5$ | $1.77X10^5$ | $1.40X10^4$ | $1.28X10^4$ |
| ICP 8859 | $1.40X10^4$ | $1.40X10^4$ | $5.94X10^4$ | $6.20X10^4$ | $4.78X10^3$ | $4.16X10^3$ |
| ICPL 89049 | $1.40X10^4$ | $1.40X10^4$ | $5.40X10^4$ | $5.70X10^4$ | $4.32X10^3$ | $3.68X10^3$ |
| DPPA 85-13 | $1.40X10^4$ | $1.40X10^4$ | $5.58X10^4$ | $5.88X10^4$ | $4.48X10^3$ | $3.83X10^3$ |
| ICPL 89048 | $1.40X10^4$ | $1.40X10^4$ | $5.36X10^4$ | $5.60X10^4$ | $4.24X10^3$ | $3.60X10^3$ |
| ICPL 87119 | $1.40X10^4$ | $1.40X10^4$ | $5.67X10^4$ | $6.00X10^4$ | $4.59X10^3$ | $3.98X10^3$ |
| AKT 8811 | $1.40X10^4$ | $1.40X10^4$ | $1.52X10^5$ | $1.66X10^5$ | $1.30X10^4$ | $1.19X10^4$ |
| CO-6 | $1.40X10^4$ | $1.40X10^4$ | $1.74X10^5$ | $1.90X10^5$ | $1.50X10^4$ | $1.37X10^4$ |
| GAUT 001E | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.89X10^5$ | $1.49X10^4$ | $1.36X10^4$ |
| GT 100 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.90X10^5$ | $1.49X10^4$ | $1.37X10^4$ |
| Pusa 84 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.92X10^5$ | $1.52X10^4$ | $1.39X10^4$ |
| AWR 74/15 | $1.40X10^4$ | $1.40X10^4$ | $5.40X10^4$ | $5.60X10^4$ | $4.00X10^3$ | $3.38X10^3$ |
| ICP 8863 | $1.40X10^4$ | $1.40X10^4$ | $4.50X10^4$ | $4.60X10^4$ | $3.28X10^3$ | $2.76X10^3$ |
| AL 15 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.90X10^5$ | $1.50X10^4$ | $1.37X10^4$ |
| Pusa 855 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.91X10^5$ | $1.50X10^4$ | $1.38X10^4$ |
| Bahar | $1.40X10^4$ | $1.40X10^4$ | $1.80X10^5$ | $2.00X10^5$ | $1.60X10^4$ | $1.50X10^4$ |
| GCP 33 | $1.40X10^4$ | $1.40X10^4$ | $5.94X10^4$ | $6.20X10^4$ | $4.96X10^3$ | $4.28X10^3$ |
| Pusa 33 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $1.88X10^5$ | $1.50X10^4$ | $1.39X10^4$ |
| Paras | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $1.90X10^5$ | $1.52X10^4$ | $1.40X10^4$ |

Table 12. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (1g) and *Meloidogyne incognita* (2000 $J_2$), singly and concomitantly in pigeonpea under field conditon

| Cultivar | At sowing | | Mid season | | Harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $1.40X10^4$ | $1.40X10^4$ | $1.53X10^5$ | $1.84X10^5$ | $1.32X10^4$ | $1.38X10^4$ |
| Manak | $1.40X10^4$ | $1.40X10^4$ | $1.58X10^5$ | $1.90X10^5$ | $1.37X10^4$ | $1.42X10^4$ |
| ICPL 87 | $1.40X10^4$ | $1.40X10^4$ | $1.75X10^5$ | $2.10X10^5$ | $1.51X10^4$ | $1.57X10^4$ |
| ICP 14722 | $1.40X10^4$ | $1.40X10^4$ | $6.03X10^4$ | $7.04X10^4$ | $1.47X10^4$ | $1.53X10^4$ |
| AL 201 | $1.40X10^4$ | $1.40X10^4$ | $1.74X10^5$ | $2.09X10^5$ | $1.50X10^4$ | $1.56X10^4$ |
| C11 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $2.07X10^5$ | $1.48X10^4$ | $1.54X10^4$ |
| Sarvodaya | $1.40X10^4$ | $1.40X10^4$ | $1.62X10^5$ | $1.94X10^5$ | $1.40X10^4$ | $1.45X10^4$ |
| ICP 8859 | $1.40X10^4$ | $1.40X10^4$ | $5.94X10^4$ | $6.82X10^4$ | $4.78X10^3$ | $4.71X10^3$ |
| ICPL 89049 | $1.40X10^4$ | $1.40X10^4$ | $5.40X10^4$ | $6.27X10^4$ | $4.32X10^3$ | $4.17X10^3$ |
| DPPA 85-13 | $1.40X10^4$ | $1.40X10^4$ | $5.58X10^4$ | $6.47X10^4$ | $4.48X10^3$ | $4.34X10^3$ |
| ICPL 89048 | $1.40X10^4$ | $1.40X10^4$ | $5.36X10^4$ | $6.16X10^4$ | $4.24X10^3$ | $4.08X10^3$ |
| ICPL 87119 | $1.40X10^4$ | $1.40X10^4$ | $5.67X10^4$ | $6.60X10^4$ | $4.59X10^3$ | $4.51X10^3$ |
| AKT 8811 | $1.40X10^4$ | $1.40X10^4$ | $1.52X10^5$ | $1.82X10^5$ | $1.30X10^4$ | $1.35X10^4$ |
| CO-6 | $1.40X10^4$ | $1.40X10^4$ | $1.74X10^5$ | $2.09X10^5$ | $1.50X10^4$ | $1.55X10^4$ |
| GAUT 001E | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $2.08X10^5$ | $1.49X10^4$ | $1.54X10^4$ |
| GT 100 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $2.09X10^5$ | $1.49X10^4$ | $1.55X10^4$ |
| Pusa 84 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $2.11X10^5$ | $1.52X10^4$ | $1.58X10^4$ |
| AWR 74/15 | $1.40X10^4$ | $1.40X10^4$ | $5.40X10^4$ | $6.16X10^4$ | $4.00X10^3$ | $3.83X10^3$ |
| ICP 8863 | $1.40X10^4$ | $1.40X10^4$ | $4.50X10^4$ | $5.06X10^4$ | $3.28X10^3$ | $3.13X10^3$ |
| AL 15 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $2.09X10^5$ | $1.50X10^4$ | $1.56X10^4$ |
| Pusa 855 | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $2.10X10^5$ | $1.50X10^4$ | $1.56X10^4$ |
| Bahar | $1.40X10^4$ | $1.40X10^4$ | $1.80X10^5$ | $2.20X10^5$ | $1.60X10^4$ | $1.70X10^4$ |
| GCP 33 | $1.40X10^4$ | $1.40X10^4$ | $5.94X10^4$ | $6.82X10^4$ | $4.96X10^3$ | $4.85X10^3$ |
| Pusa 33 | $1.40X10^4$ | $1.40X10^4$ | $1.72X10^5$ | $2.07X10^5$ | $1.50X10^4$ | $1.57X10^4$ |
| Paras | $1.40X10^4$ | $1.40X10^4$ | $1.73X10^5$ | $2.09X10^5$ | $1.52X10^4$ | $1.58X10^4$ |

Table 13.Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (2g) and *Meloidogyne incognita* ($500J_2$), singly and concomitantly in pigeonpea under field condition

| Cultivar | At sowing | | Mid season | | Harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^8$ | $2.00X10^8$ | $2.72X10^{10}$ | $3.34X10^{10}$ | $2.15X10^8$ | $2.19X10^8$ |
| Manak | $2.00X10^8$ | $2.00X10^8$ | $2.82X10^{10}$ | $3.46X10^{10}$ | $2.23X10^8$ | $2.26X10^8$ |
| ICPL 87 | $2.00X10^8$ | $2.00X10^8$ | $3.10X10^{10}$ | $3.82X10^{10}$ | $2.45X10^8$ | $2.50X10^8$ |
| ICP 14722 | $2.00X10^8$ | $2.00X10^8$ | $1.07X10^{10}$ | $1.28X10^{10}$ | $2.39X10^8$ | $2.43X10^8$ |
| AL 201 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $3.80X10^{10}$ | $2.43X10^8$ | $2.47X10^8$ |
| C11 | $2.00X10^8$ | $2.00X10^8$ | $3.06X10^{10}$ | $3.76X10^{10}$ | $2.41X10^8$ | $2.45X10^8$ |
| Sarvodaya | $2.00X10^8$ | $2.00X10^8$ | $2.88X10^{10}$ | $3.54X10^{10}$ | $2.27X10^8$ | $2.30X10^8$ |
| ICP 8859 | $2.00X10^8$ | $2.00X10^8$ | $1.06X10^{10}$ | $1.24X10^{10}$ | $7.77X10^7$ | $7.48X10^7$ |
| ICPL 89049 | $2.00X10^8$ | $2.00X10^8$ | $9.60X10^9$ | $1.14X10^{10}$ | $7.02X10^7$ | $6.62X10^7$ |
| DPPA 85-13 | $2.00X10^8$ | $2.00X10^8$ | $9.92X10^9$ | $1.18X10^{10}$ | $7.28X10^7$ | $6.89X10^7$ |
| ICPL 89048 | $2.00X10^8$ | $2.00X10^8$ | $9.54X10^9$ | $1.12X10^{10}$ | $6.89X10^7$ | $6.48X10^7$ |
| ICPL 87119 | $2.00X10^8$ | $2.00X10^8$ | $1.01X10^{10}$ | $1.20X10^{10}$ | $7.46X10^7$ | $7.16X10^7$ |
| AKT 8811 | $2.00X10^8$ | $2.00X10^8$ | $2.70X10^{10}$ | $3.31X10^{10}$ | $2.11X10^8$ | $2.14X10^8$ |
| CO-6 | $2.00X10^8$ | $2.00X10^8$ | $3.09X10^{10}$ | $3.79X10^{10}$ | $2.43X10^8$ | $2.47X10^8$ |
| GAUT 001E | $2.00X10^8$ | $2.00X10^8$ | $3.06X10^{10}$ | $3.78X10^{10}$ | $2.42X10^8$ | $2.45X10^8$ |
| GT 100 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $3.81X10^{10}$ | $2.43X10^8$ | $2.47X10^8$ |
| Pusa 84 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $3.84X10^{10}$ | $2.46X10^8$ | $2.50X10^8$ |
| AWR 74/15 | $2.00X10^8$ | $2.00X10^8$ | $9.60X10^9$ | $1.12X10^{10}$ | $6.50X10^7$ | $6.08X10^7$ |
| ICP 8863 | $2.00X10^8$ | $2.00X10^8$ | $8.00X10^9$ | $9.20X10^9$ | $5.33X10^7$ | $4.97X10^7$ |
| AL 15 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $3.80X10^{10}$ | $2.43X10^8$ | $2.47X10^8$ |
| Pusa 855 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $3.82X10^{10}$ | $2.44X10^8$ | $2.48X10^8$ |
| Bahar | $2.00X10^8$ | $2.00X10^8$ | $3.20X10^{10}$ | $4.00X10^{10}$ | $2.60X10^8$ | $2.70X10^8$ |
| GCP 33 | $2.00X10^8$ | $2.00X10^8$ | $1.06X10^{10}$ | $1.24X10^{10}$ | $8.06X10^7$ | $7.70X10^7$ |
| Pusa 33 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $3.76X10^{10}$ | $2.44X10^8$ | $2.50X10^8$ |
| Paras | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $3.79X10^{10}$ | $2.46X10^8$ | $2.51X10^8$ |

Table 15. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (2g) and *Meloidogyne incognita* (2000 $J_2$), singly and concomitantly in pigeonpea under field conditon

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.40X10^{16}$ | $4.51X10^{16}$ | $2.48X10^{16}$ | $2.51X10^{16}$ |
| Manak | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.52X10^{16}$ | $4.67X10^{16}$ | $2.57X10^{16}$ | $2.59X10^{16}$ |
| ICPL 87 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.88X10^{16}$ | $5.16X10^{16}$ | $2.83X10^{16}$ | $2.87X10^{16}$ |
| ICP 14722 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.34X10^{16}$ | $1.73X10^{16}$ | $2.76X10^{16}$ | $2.79X10^{16}$ |
| AL 201 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $5.13X10^{16}$ | $2.81X10^{16}$ | $2.84X10^{16}$ |
| C11 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.08X10^{16}$ | $2.78X10^{16}$ | $2.81X10^{16}$ |
| Sarvodaya | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.60X10^{16}$ | $4.77X10^{16}$ | $2.62X10^{16}$ | $2.64X10^{16}$ |
| ICP 8859 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.67X10^{16}$ | $8.97X10^{15}$ | $8.59X10^{15}$ |
| ICPL 89049 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.54X10^{16}$ | $8.10X10^{15}$ | $7.60X10^{15}$ |
| DPPA 85-13 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.24X10^{16}$ | $1.59X10^{16}$ | $8.40X10^{15}$ | $7.91X10^{15}$ |
| ICPL 89048 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.19X10^{16}$ | $1.51X10^{16}$ | $7.95X10^{15}$ | $7.44X10^{15}$ |
| ICPL 87119 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.26X10^{16}$ | $1.62X10^{16}$ | $8.61X10^{15}$ | $8.22X10^{15}$ |
| AKT 8811 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.38X10^{16}$ | $4.47X10^{16}$ | $2.44X10^{16}$ | $2.46X10^{16}$ |
| CO-6 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $5.12X10^{16}$ | $2.81X10^{16}$ | $2.83X10^{16}$ |
| GAUT 001E | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.10X10^{16}$ | $2.79X10^{16}$ | $2.81X10^{16}$ |
| GT 100 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.14X10^{16}$ | $2.80X10^{16}$ | $2.83X10^{16}$ |
| Pusa 84 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.18X10^{16}$ | $2.84X10^{16}$ | $2.87X10^{16}$ |
| AWR 74/15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.51X10^{16}$ | $7.50X10^{15}$ | $6.98X10^{15}$ |
| ICP 8863 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.00X10^{16}$ | $1.24X10^{16}$ | $6.15X10^{15}$ | $5.70X10^{15}$ |
| AL 15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.85X10^{16}$ | $5.13X10^{16}$ | $2.81X10^{16}$ | $2.84X10^{16}$ |
| Pusa 855 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.15X10^{16}$ | $2.82X10^{16}$ | $2.85X10^{16}$ |
| Bahar | $2.00X10^{16}$ | $2.00X10^{16}$ | $4.00X10^{16}$ | $5.40X10^{16}$ | $3.00X10^{16}$ | $3.10X10^{16}$ |
| GCP 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.67X10^{16}$ | $9.30X10^{15}$ | $8.84X10^{15}$ |
| Pusa 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.08X10^{16}$ | $2.82X10^{16}$ | $2.87X10^{16}$ |
| Paras | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.12X10^{16}$ | $2.84X10^{16}$ | $2.89X10^{16}$ |

Table 16. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (4g) and *Meloidogyne incognita* (500 $J_2$), singly and concomitantly in pigeonpea under field conditon

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.40X10^{16}$ | $4.18X10^{16}$ | $2.48X10^{16}$ | $2.47X10^{16}$ |
| Manak | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.52X10^{16}$ | $4.32X10^{16}$ | $2.57X10^{16}$ | $2.55X10^{16}$ |
| ICPL 87 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.88X10^{16}$ | $4.78X10^{16}$ | $2.83X10^{16}$ | $2.82X10^{16}$ |
| ICP 14722 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.34X10^{16}$ | $1.60X10^{16}$ | $2.76X10^{16}$ | $2.75X10^{16}$ |
| AL 201 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $4.75X10^{16}$ | $2.81X10^{16}$ | $2.79X10^{16}$ |
| C11 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $4.70X10^{16}$ | $2.78X10^{16}$ | $2.77X10^{16}$ |
| Sarvodaya | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.60X10^{16}$ | $4.42X10^{16}$ | $2.62X10^{16}$ | $2.60X10^{16}$ |
| ICP 8859 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.55X10^{16}$ | $8.97X10^{15}$ | $8.45X10^{15}$ |
| ICPL 89049 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.43X10^{16}$ | $8.10X10^{15}$ | $7.47X10^{15}$ |
| DPPA 85-13 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.24X10^{16}$ | $1.47X10^{16}$ | $8.40X10^{15}$ | $7.78X10^{15}$ |
| ICPL 89048 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.19X10^{16}$ | $1.40X10^{16}$ | $7.95X10^{15}$ | $7.32X10^{15}$ |
| ICPL 87119 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.26X10^{16}$ | $1.50X10^{16}$ | $8.61X10^{15}$ | $8.08X10^{15}$ |
| AKT 8811 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.38X10^{16}$ | $4.14X10^{16}$ | $2.44X10^{16}$ | $2.42X10^{16}$ |
| CO-6 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $4.74X10^{16}$ | $2.81X10^{16}$ | $2.79X10^{16}$ |
| GAUT 001E | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $4.73X10^{16}$ | $2.79X10^{16}$ | $2.77X10^{16}$ |
| GT 100 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $4.76X10^{16}$ | $2.80X10^{16}$ | $2.78X10^{16}$ |
| Pusa 84 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $4.80X10^{16}$ | $2.84X10^{16}$ | $2.83X10^{16}$ |
| AWR 74/15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.40X10^{16}$ | $7.50X10^{15}$ | $6.86X10^{15}$ |
| ICP 8863 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.00X10^{16}$ | $1.15X10^{16}$ | $6.15X10^{15}$ | $5.61X10^{15}$ |
| AL 15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.85X10^{16}$ | $4.75X10^{16}$ | $2.81X10^{16}$ | $2.79X10^{16}$ |
| Pusa 855 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $4.77X10^{16}$ | $2.82X10^{16}$ | $2.80X10^{16}$ |
| Bahar | $2.00X10^{16}$ | $2.00X10^{16}$ | $4.00X10^{16}$ | $5.00X10^{16}$ | $3.00X10^{16}$ | $3.05X10^{16}$ |
| GCP 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.55X10^{16}$ | $9.30X10^{15}$ | $8.69X10^{15}$ |
| Pusa 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $4.70X10^{16}$ | $2.82X10^{16}$ | $2.82X10^{16}$ |
| Paras | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $4.74X10^{16}$ | $2.84X10^{16}$ | $2.84X10^{16}$ |

Table 14. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (2g) and *Meloidogyne incognita* (1000 $J_2$), singly and concomitantly in pigeonpea under field conditon

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^8$ | $2.00X10^8$ | $2.72X10^{10}$ | $3.51X10^{10}$ | $2.15X10^8$ | $2.23X10^8$ |
| Manak | $2.00X10^8$ | $2.00X10^8$ | $2.82X10^{10}$ | $3.63X10^{10}$ | $2.23X10^8$ | $2.30X10^8$ |
| ICPL 87 | $2.00X10^8$ | $2.00X10^8$ | $3.10X10^{10}$ | $4.01X10^{10}$ | $2.45X10^8$ | $2.54X10^8$ |
| ICP 14722 | $2.00X10^8$ | $2.00X10^8$ | $1.07X10^{10}$ | $1.34X10^{10}$ | $2.39X10^8$ | $2.48X10^8$ |
| AL 201 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $3.99X10^{10}$ | $2.43X10^8$ | $2.52X10^8$ |
| C11 | $2.00X10^8$ | $2.00X10^8$ | $3.06X10^{10}$ | $3.95X10^{10}$ | $2.41X10^8$ | $2.49X10^8$ |
| Sarvodaya | $2.00X10^8$ | $2.00X10^8$ | $2.88X10^{10}$ | $3.71X10^{10}$ | $2.27X10^8$ | $2.34X10^8$ |
| ICP 8859 | $2.00X10^8$ | $2.00X10^8$ | $1.06X10^{10}$ | $1.30X10^{10}$ | $7.77X10^7$ | $7.62X10^7$ |
| ICPL 89049 | $2.00X10^8$ | $2.00X10^8$ | $9.60X10^9$ | $1.20X10^{10}$ | $7.02X10^7$ | $6.74X10^7$ |
| DPPA 85-13 | $2.00X10^8$ | $2.00X10^8$ | $9.92X10^9$ | $1.23X10^{10}$ | $7.28X10^7$ | $7.01X10^7$ |
| ICPL 89048 | $2.00X10^8$ | $2.00X10^8$ | $9.54X10^9$ | $1.18X10^{10}$ | $6.89X10^7$ | $6.60X10^7$ |
| ICPL 87119 | $2.00X10^8$ | $2.00X10^8$ | $1.01X10^{10}$ | $1.26X10^{10}$ | $7.46X10^7$ | $7.29X10^7$ |
| AKT 8811 | $2.00X10^8$ | $2.00X10^8$ | $2.70X10^{10}$ | $3.48X10^{10}$ | $2.11X10^8$ | $2.18X10^8$ |
| CO-6 | $2.00X10^8$ | $2.00X10^8$ | $3.09X10^{10}$ | $3.98X10^{10}$ | $2.43X10^8$ | $2.51X10^8$ |
| GAUT 001E | $2.00X10^8$ | $2.00X10^8$ | $3.06X10^{10}$ | $3.97X10^{10}$ | $2.42X10^8$ | $2.49X10^8$ |
| GT 100 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $4.00X10^{10}$ | $2.43X10^8$ | $2.51X10^8$ |
| Pusa 84 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $4.03X10^{10}$ | $2.46X10^8$ | $2.55X10^8$ |
| AWR 74/15 | $2.00X10^8$ | $2.00X10^8$ | $9.60X10^9$ | $1.18X10^{10}$ | $6.50X10^7$ | $6.19X10^7$ |
| ICP 8863 | $2.00X10^8$ | $2.00X10^8$ | $8.00X10^9$ | $9.66X10^9$ | $5.33X10^7$ | $5.06X10^7$ |
| AL 15 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $3.99X10^{10}$ | $2.43X10^8$ | $2.52X10^8$ |
| Pusa 855 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $4.01X10^{10}$ | $2.44X10^8$ | $2.53X10^8$ |
| Bahar | $2.00X10^8$ | $2.00X10^8$ | $3.20X10^{10}$ | $4.20X10^{10}$ | $2.60X10^8$ | $2.75X10^8$ |
| GCP 33 | $2.00X10^8$ | $2.00X10^8$ | $1.06X10^{10}$ | $1.30X10^{10}$ | $8.06X10^7$ | $7.84X10^7$ |
| Pusa 33 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $3.95X10^{10}$ | $2.44X10^8$ | $2.54X10^8$ |
| Paras | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $3.98X10^{10}$ | $2.46X10^8$ | $2.56X10^8$ |

Table 17. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (4g) and *Meloidogyne incognita* (1000 $J_2$), singly and concomitantly in pigeonpea under field conditon

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.40X10^{16}$ | $4.51X10^{16}$ | $2.48X10^{16}$ | $2.51X10^{16}$ |
| Manak | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.52X10^{16}$ | $4.67X10^{16}$ | $2.57X10^{16}$ | $2.59X10^{16}$ |
| ICPL 87 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.88X10^{16}$ | $5.16X10^{16}$ | $2.83X10^{16}$ | $2.87X10^{16}$ |
| ICP 14722 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.34X10^{16}$ | $1.73X10^{16}$ | $2.76X10^{16}$ | $2.79X10^{16}$ |
| AL 201 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $5.13X10^{16}$ | $2.81X10^{16}$ | $2.84X10^{16}$ |
| C11 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.08X10^{16}$ | $2.78X10^{16}$ | $2.81X10^{16}$ |
| Sarvodaya | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.60X10^{16}$ | $4.77X10^{16}$ | $2.62X10^{16}$ | $2.64X10^{16}$ |
| ICP 8859 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.67X10^{16}$ | $8.97X10^{15}$ | $8.59X10^{15}$ |
| ICPL 89049 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.54X10^{16}$ | $8.10X10^{15}$ | $7.60X10^{15}$ |
| DPPA 85-13 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.24X10^{16}$ | $1.59X10^{16}$ | $8.40X10^{15}$ | $7.91X10^{15}$ |
| ICPL 89048 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.19X10^{16}$ | $1.51X10^{16}$ | $7.95X10^{15}$ | $7.44X10^{15}$ |
| ICPL 87119 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.26X10^{16}$ | $1.62X10^{16}$ | $8.61X10^{15}$ | $8.22X10^{15}$ |
| AKT 8811 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.38X10^{16}$ | $4.47X10^{16}$ | $2.44X10^{16}$ | $2.46X10^{16}$ |
| CO-6 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $5.12X10^{16}$ | $2.81X10^{16}$ | $2.83X10^{16}$ |
| GAUT 001E | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.10X10^{16}$ | $2.79X10^{16}$ | $2.81X10^{16}$ |
| GT 100 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.14X10^{16}$ | $2.80X10^{16}$ | $2.83X10^{16}$ |
| Pusa 84 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.18X10^{16}$ | $2.84X10^{16}$ | $2.87X10^{16}$ |
| AWR 74/15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.51X10^{16}$ | $7.50X10^{15}$ | $6.98X10^{15}$ |
| ICP 8863 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.00X10^{16}$ | $1.24X10^{16}$ | $6.15X10^{15}$ | $5.70X10^{15}$ |
| AL 15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.85X10^{16}$ | $5.13X10^{16}$ | $2.81X10^{16}$ | $2.84X10^{16}$ |
| Pusa 855 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.15X10^{16}$ | $2.82X10^{16}$ | $2.85X10^{16}$ |
| Bahar | $2.00X10^{16}$ | $2.00X10^{16}$ | $4.00X10^{16}$ | $5.40X10^{16}$ | $3.00X10^{16}$ | $3.10X10^{16}$ |
| GCP 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.67X10^{16}$ | $9.30X10^{15}$ | $8.84X10^{15}$ |
| Pusa 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.08X10^{16}$ | $2.82X10^{16}$ | $2.87X10^{16}$ |
| Paras | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.12X10^{16}$ | $2.84X10^{16}$ | $2.89X10^{16}$ |

Table 18. Rhizoshpere population (CFUs) of *Fusarium udum* after the inoculation of fungus (4g) and *Meloidogyne incognita* (2000 $J_2$), singly and concomitantly in pigeonpea under field conditon

| Cultivar | At sowing | | Mid season | | harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.40X10^{16}$ | $5.01X10^{16}$ | $2.48X10^{16}$ | $2.84X10^{16}$ |
| Manak | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.52X10^{16}$ | $5.18X10^{16}$ | $2.57X10^{16}$ | $2.93X10^{16}$ |
| ICPL 87 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.88X10^{16}$ | $5.73X10^{16}$ | $2.83X10^{16}$ | $3.24X10^{16}$ |
| ICP 14722 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.34X10^{16}$ | $1.92X10^{16}$ | $2.76X10^{16}$ | $3.15X10^{16}$ |
| AL 201 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $5.70X10^{16}$ | $2.81X10^{16}$ | $3.20X10^{16}$ |
| C11 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.64X10^{16}$ | $2.78X10^{16}$ | $3.17X10^{16}$ |
| Sarvodaya | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.60X10^{16}$ | $5.30X10^{16}$ | $2.62X10^{16}$ | $2.98X10^{16}$ |
| ICP 8859 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.86X10^{16}$ | $8.97X10^{15}$ | $9.70X10^{15}$ |
| ICPL 89049 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.71X10^{16}$ | $8.10X10^{15}$ | $8.58X10^{15}$ |
| DPPA 85-13 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.24X10^{16}$ | $1.76X10^{16}$ | $8.40X10^{15}$ | $8.93X10^{15}$ |
| ICPL 89048 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.19X10^{16}$ | $1.68X10^{16}$ | $7.95X10^{15}$ | $8.40X10^{15}$ |
| ICPL 87119 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.26X10^{16}$ | $1.80X10^{16}$ | $8.61X10^{15}$ | $9.28X10^{15}$ |
| AKT 8811 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.38X10^{16}$ | $4.97X10^{16}$ | $2.44X10^{16}$ | $2.78X10^{16}$ |
| CO-6 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.86X10^{16}$ | $5.69X10^{16}$ | $2.81X10^{16}$ | $3.20X10^{16}$ |
| GAUT 001E | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.67X10^{16}$ | $2.79X10^{16}$ | $3.17X10^{16}$ |
| GT 100 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.71X10^{16}$ | $2.80X10^{16}$ | $3.20X10^{16}$ |
| Pusa 84 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.76X10^{16}$ | $2.84X10^{16}$ | $3.24X10^{16}$ |
| AWR 74/15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.20X10^{16}$ | $1.68X10^{16}$ | $7.50X10^{15}$ | $7.88X10^{15}$ |
| ICP 8863 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.00X10^{16}$ | $1.38X10^{16}$ | $6.15X10^{15}$ | $6.44X10^{15}$ |
| AL 15 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.85X10^{16}$ | $5.70X10^{16}$ | $2.81X10^{16}$ | $3.20X10^{16}$ |
| Pusa 855 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.72X10^{16}$ | $2.82X10^{16}$ | $3.22X10^{16}$ |
| Bahar | $2.00X10^{16}$ | $2.00X10^{16}$ | $4.00X10^{16}$ | $6.00X10^{16}$ | $3.00X10^{16}$ | $3.50X10^{16}$ |
| GCP 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $1.32X10^{16}$ | $1.86X10^{16}$ | $9.30X10^{15}$ | $9.98X10^{15}$ |
| Pusa 33 | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.83X10^{16}$ | $5.64X10^{16}$ | $2.82X10^{16}$ | $3.24X10^{16}$ |
| Paras | $2.00X10^{16}$ | $2.00X10^{16}$ | $3.84X10^{16}$ | $5.69X10^{16}$ | $2.84X10^{16}$ | $3.26X10^{16}$ |

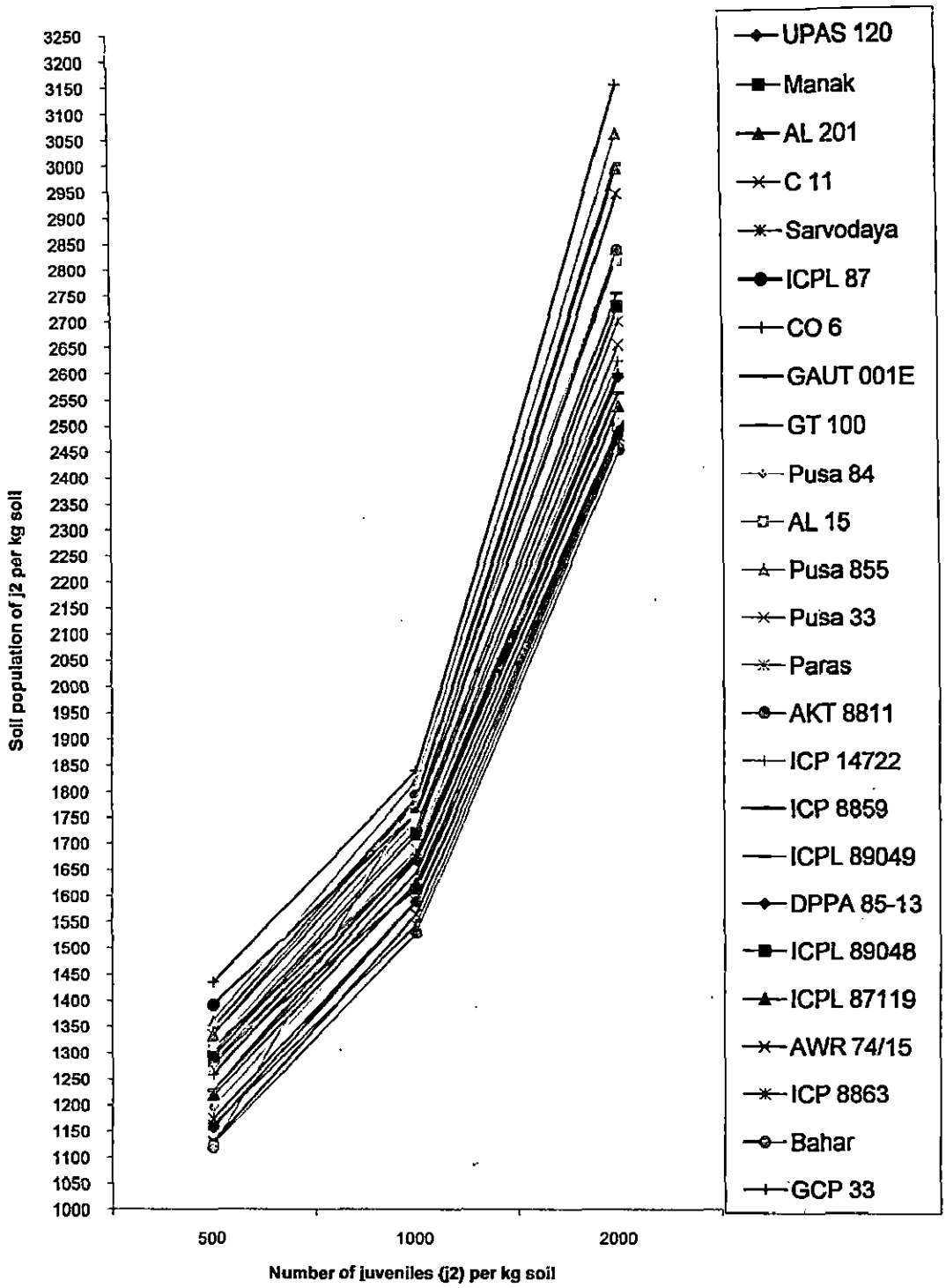


**Fig.14 Effect of inoculation with *Meloidogyne incognita* on soil population of nematodes in pigeonpea under pot culture condition.**

Table 19. Integrated nematode management and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on wilt severity (%) in pigeonpea plants under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 I2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 0.00 | 32.00 | 0.00 | 50.6 (25.3) |
| Dimethoate | 0.00 | 30.60 (4.40) | 0.00 | 47.2 (54.2) (6.72) |
| *Calotropis procera* | 0.00 | 21.80 (31.90) | 0.00 | 30.5 (39.9) (39.70) |
| Neem Seed Powder | 0.00 | 18.33 (42.80) | 0.00 | 29.8 (62.8) (41.10) |
| Dimethoate + *C. procera* | 0.00 | 17.50 (45.30) | 0.00 | 27.8 (58.9) (45.10) |
| *C. procera* + Neem Seed Powder | 0.00 | 15.80 (50.60) | 0.00 | 25.2 (59.5) (50.20) |
| Dimethoate + Neem Seed Powder | 0.00 | 15.80 (50.60) | 0.00 | 27.1 (71.5) (46.40) |
| Dimethoate + Neem Seed Powder + *C. procera* | 0.00 | 13.80 (56.90) | 0.00 | 18.9 (36.9) (62.60) |
| CD $P \leq 0.05$ | | 1.70 | | 7.10 |
| $P \leq 0.01$ | | 2.30 | | 9.60 |
| *F*- value | | | | |
| Control Treatments (df = 7) | : | 6.16 | | |
| Fungus (df = 1) | : | 1337.69 | | |
| Nematode (df = 1) | : | 61.63 | | |
| Treatments x Fungus (df = 7) | : | 6.16 | | |
| Treatments x Nematode (df = 7) | : | 61.63 | | |
| Fungus x nematodes (df = 1) | : | 0.53 | | |
| Treatments x Fungus x Nematode (df = 7) | : | 0.53 | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 20. Integrated nematode management and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the number of root galls in pigeonpea under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 0.00 | 0.00 | 27.00 | 20 (25.93) |
| Dimethoate | 0.00 | 0.00 | 23.00 (14.81) | 17 (26.09) (15.00) |
| *Calotropis procera* | 0.00 | 0.00 | 19.00 (29.63) | 15 (21.05) (25.00) |
| Neem Seed Powder | 0.00 | 0.00 | 17.00 (37.04) | 14 (17.65) (30.00) |
| Dimethoate + *C. procera* | 0.00 | 0.00 | 15.00 (44.44) | 13 (13.33) (35.00) |
| *C. procera* + Neem Seed Powder | 0.00 | 0.00 | 13.00 (51.85) | 10 (23.08) (50.00) |
| Dimethoate + Neem Seed Powder | 0.00 | 0.00 | 14.00 (48.15) | 12 (14.29) (40.00) |
| Dimethoate + Neem Seed Powder + *C. procera* | 0.00 | 0.00 | 10.00 (62.96) | 8 (20.00) (60.00) |
| CD $P \leq 0.05$ | | | 1.80 | 2.54 |
| $P \leq 0.01$ | | | 2.53 | 3.58 |
| *F*- value | | | 31.15 | 1.09 |

| | | |
|---|---|---|
| Control Treatments (df = 7) | : | 25.94 |
| Fungus (df = 1) | : | 31.15 |
| Nematode (df = 1) | : | 2259.59 |
| Treatments x Fungus (df = 7) | : | 1.09 |
| Treatments x Nematode (df = 7) | : | 31.15 |
| Fungus x nematodes (df = 1) | : | 25.94 |
| Treatments x Fungus x Nematode (df = 7) | : | 1.09 |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

## Experiment 2

### 4.3 Effect of seeds treatment with different materials on the interaction of root-knot nematode *Meloidogyne incognita* and wilt fungus *Fusarium udum* on pigeonpea cv. UPAS 120 under pot condition.

Interaction of *M. incognita* and *F. udum* was investigated on pigeonpea cv. UPAS 120 under pot condition to ascertain the effect of seed treatment with different material. Inoculation with the pigeon pea was done by applying 2g fungus colonized seed/kg soil and 2000 juveniles of *Meloidogyne incognita*/kg soil singly and concomitantly.

### 4.4 Symptoms

#### 4.4.1 Fusarial wilt

Plants grown in pot inoculated with sorghum seeds colonized by *F. udum* expressed wilt symptoms. Wilt severity was 32% in untreated seeds when grown in pots inoculated with *F. udum* alone (Table 19). The disease severity increased (50.6%) when both the pathogens i.e. *F. udum* and *M. incognita* was applied concomitantly. All the treatments viz. Dimethoate, *Calotropis procera*, Neem seed powder, Dimethoate + *C. procera*, Dimethoate + Neem seed powder, *C. procera* + Neem seed powder, Dimethoate + Neem seed powder + *C. procera* reduced the wilting of seedlings. Most effective combination as seed treatment was Dimethoate + Neem seed powder + *C. procera* which showed 56.9% reduction ($p \leq 0.01$) in wilting followed by *C. procera* + Neem seed powder and Dimethoate + Neem seed powder (50.6% each) over untreated control in case of those seedlings where soil inoculation was done with *F. udum* alone. Seed treatment with Dimethoate + Neem seed powder + *C. procera* was also found most effective in reducing wilt severity where seedlings were grown in soil inoculated with *F. udum* and *M. incognita* concomitantly.

#### 4.4.2 Root-Knot

Plants grown from untreated seeds showed stunted growth and dull green foliage. Galls were observed on roots when plants were uprooted at maturity. In pots where soil was inoculated with *M. incognita* alone the plants of untreated seeds were found with highest number (27) of root galls. A 14.8% ($P \leq 0.01$) decrease in the number of galls were recorded when seed treatment was done with Dimethoate. Greatest decrease (63%) ($P \leq 0.01$) was observed in Dimethoate + Neem seed powder + *C. procera* followed by *C. procera* + Neem seed powder (51.9%) over untreated seeds (Table 20). The number of

galls decreased (25.9%) when soil application of *M. incognita* was done simultaneously with *F. udum* as compared to *M. incognita* alone in case of untreated seeds. A 60% ($P \leq 0.01$) decrease in root galls were observed in plants grown from the seeds treated with a combination of Dimethoate + Neem seed powder + *C. procera* as compared to plants of untreated seeds in presence of both the pathogens (*F. udum* + *M. incognita*). Eggs mass per root system decreased in all the treatments as compared to control in both the case where soil inoculation was done with *M. incognita* alone and in combination with *F. udum* (Table 21).

A decrease of 71.4% ($P \leq 0.01$) egg mass per root system was recorded in plants grown from the seeds treated with Dimethoate + Neem seed powder + *C. procera* over control, where soil inoculation was done with *M. incognita* alone. In the same combination of seed treatment there was 33.3% decrease in egg mass per root system when *M. incognita* was applied simultaneously with *F. udum* in soil.

### 4.4.3 Plant growth and yield

Inoculation with *F. udum* and *M. incognita* alone suppressed dry weight of plants upto 4.8% and 8.5% over control in untreated seeds. However simultaneous application of both the organisms decreased the dry weight of plant by 10.9% (Table 22). Seed treatment with Dimethoate + Neem seed powder + *C. procera* decreased the dry weight to 0.6% over control in case of both the pathogens *F. udum* and *M. incognita* when applied alone in soil. However, simultaneous application of both the pathogens resulted in 2.4% decrease over control in dry weight of plant in the above combination. The dry weight increased by 5.7 and 5.1% ($P \leq 0.05$) when seed treatment was done with Dimethoate + Neem seed powder + *C. procera* and *C. procera* + Neem seed powder, respectively as compared to untreated seeds in case of plants of those pots where soil inoculation was done with *F. udum* alone. The lowest increase was found in Dimethoate (1.3%). The above combination of seed treatment showed the same trend of increase in dry weight of plants when soil inoculation was done with *M. incognita* alone. Maximum increase 9.9% ($P \leq 0.01$) was found in Dimethoate + Neem seed powder + *C. procera* followed by *C. procera* + Neem seed powder (9.3%) ($P \leq 0.01$). When both the pathogens *F. udum* and *M. incognita* was applied concomitantly, again the best combination was Dimethoate + Neem seed powder + *C. procera* which resulted in 10.9 % ($P \leq 0.01$) increase in dry weight of plants followed by *C. procera* + Neem seed powder (10.2%) as compared to untreated seeds.

Table 21. Integrated nematode management and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on egg masses per root system in pigeonpea under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 0.00 | 0.00 | 21.00 | 11.00 (47.62) |
| Dimethoate | 0.00 | 0.00 | 17.00 (19.05) | 10.67 (37.24) (3.00) |
| *Calotropis procera* | 0.00 | 0.00 | 14.00 (33.33) | 8.67 (38.07) (21.18) |
| Neem Seed Powder | 0.00 | 0.00 | 12.00 (42.86) | 8.67 (27.75) (21.18) |
| Dimethoate + *C. procera* | 0.00 | 0.00 | 10.00 (52.38) | 6.67 (33.30) (39.36) |
| *C. procera* + Neem Seed Powder | 0.00 | 0.00 | 8.00 (61.90) | 5.33 (33.38) (51.55) |
| Dimethoate + Neem Seed Powder | 0.00 | 0.00 | 10.00 (52.38) | 6.00 (40.00) (45.45) |
| Dimethoate + Neem Seed Powder + *C. procera* | 0.00 | 0.00 | 6.00 (71.43) | 4.00 (33.33) (63.64) |
| CD $P \leq 0.05$<br>$P \leq 0.01$ | | | 1.82<br>2.56 | 2.57<br>3.62 |
| *F*- value | | | 47.71 | 1.65 |

| | | |
|---|---|---|
| Control Treatments (df = 7) | : | 16.45 |
| Fungus (df = 1) | : | 47.71 |
| Nematode (df = 1) | : | 921.45 |
| Treatments x Fungus (df = 7) | : | 1.65 |
| Treatments x Nematode (df = 7) | : | 47.71 |
| Fungus x nematodes (df = 1) | : | 16.45 |
| Treatments x Fungus x Nematode (df = 7) | : | 1.65 |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 22. Integrated nematode management and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on dry weight of pigeonpea plants under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 1.65 | 1.57 (4.85) | 1.57 (8.48) | 1.47 (10.91) |
| Dimethoate | 1.65<br>0.00 | 1.59 (3.64)<br>(1.27) | 1.58 (4.24)<br>(4.64) | 1.53 (7.27)<br>(4.08) |
| *Calotropis procera* | 1.70<br>(3.03) | 1.65 (2.94)<br>(5.10) | 1.64 (3.53)<br>(8.61) | 1.56 (8.24)<br>(6.12) |
| Neem Seed Powder | 1.74<br>(5.45) | 1.72 (1.15)<br>(9.55) | 1.68 (3.45)<br>(11.26) | 1.59 (8.62)<br>(8.16) |
| Dimethoate + *C. procera* | 1.80<br>(9.09) | 1.76 (2.22)<br>(12.10) | 1.73 (3.89)<br>(14.57) | 1.65 (8.33)<br>(12.24) |
| *C. procera* + Neem Seed Powder | 1.87<br>(13.33) | 1.80 (3.74)<br>(14.65) | 1.80 (3.74)<br>(19.21) | 1.71 (8.56)<br>(16.33) |
| Dimethoate + Neem Seed Powder | 1.82<br>(10.30) | 1.76 (3.30)<br>(12.10) | 1.76 (3.30)<br>(16.56) | 1.66 (8.79)<br>(12.93) |
| Dimethoate + Neem Seed Powder + *C. procera* | 1.94<br>(17.58) | 1.85 (4.64)<br>(17.83) | 1.85 (4.64)<br>(22.52) | 1.77 (8.76)<br>(20.41) |
| CD $P \leq 0.05$<br>$P \leq 0.01$ | 0.04<br>0.06 | 0.02<br>0.30 | 0.06<br>0.08 | 0.08<br>0.12 |
| *F*- value | 43.92 | 59.34 | 0.65 | 0.32 |

| | | |
|---|---|---|
| Control Treatments (df = 7) | : | 43.92 |
| Fungus (df = 1) | : | 37.03 |
| Nematode (df = 1) | : | 59.34 |
| Treatments x Fungus (df = 7) | : | 0.14 |
| Treatments x Nematode (df = 7) | : | 0.65 |
| Fungus x nematodes (df = 1) | : | 0.26 |
| Treatments x Fungus x Nematode (df = 7) | : | 0.32 |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Yield suppression was highest in plants where soil inoculation was done with *F. udum* and *M. incognita* simultaneously than either of the pathogens alone (Table 23). Yield suppression was 18.3%, 21.7% and 35% where the soil was inoculated with *F. udum*, *M. incognita*, and *F. udum* + *M. incognita*, respectively in untreated seeds as compared to control.

Yield decrease was lowest where seed treatment was done with Dimethoate + Neem seed powder + *C. procera*. It was 4.8% in *F. udum* and *M. incognita* and 6.3% ($P \leq 0.01$) in *F. udum* + *M. incognita* inoculated soil followed by *C. procera* + Neem seed powder where it was 6.3%, 9.4% and 10.9% in *F. udum*, *M. incognita* and *F. udum* + *M. incognita*, respectively as compared to control. Increase in yield up to 22.4, 22.7 and 51.2% ($P \leq 0.01$) in *F. udum*, *M. incognita* and *F. udum* + *M. incognita*, respectively was recorded where seed treatment was done with Dimethoate + Neem seed powder + *C. procera* as compared to untreated seeds. The next better combination as seed treatment was *C. procera* + Neem seed powder where yield increased up to 22.4, 27.7 and 46.2% ($P \leq 0.01$) in *F. udum*, *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds.

Among all the seed treatment options used the lowest increase was found in Dimethoate, which resulted in 4.1, 4.3 and 10.3% increase in yield (not significant) in *F. udum*, *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds.

### 4.4.4 Root nodulation

Plant grown from the treated seeds showed good nodulation as compared to plants of untreated seeds. The best combination as seed treatment was Dimethoate + Neem seed powder + *C. procera* which resulted in 13.2, 25.3 and 39.8% ($P \leq 0.01$) increase in root nodulation in *F. udum*, *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds ( Table 24). The second best combination for seed treatment was found *C. procera* + Neem seed powder ($P \leq 0.01$) which resulted an increase in root nodulation up to 10.5, 22.3 and 33% in *F. udum*, *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds. There was no increase in root nodulation of plat grown from Dimethoate treated seeds where the soil inoculation was done with *F. udum* alone. However 4.9 and 9.1% increase in root nodulation was recorded in *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds.

Table 23. Integrated nematode management and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on grain weight (g) / plant of pigeonpea under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 6.02 | 4.87 (19.10) | 3.30 (45.18) | 3.04 (49.50) |
| Dimethoate | 6.00 (-0.33) | 4.90 (18.33) (0.62) | 3.93 (34.50) (19.09) | 3.67 (38.83) (20.72) |
| *Calotropis procera* | 6.00 (-0.33) | 5.07 (15.50) (4.11) | 4.10 (31.67) (24.24) | 3.70 (38.33) (21.71) |
| Neem Seed Powder | 6.33 (5.14) | 5.23 (17.38) (7.39) | 4.40 (30.49) (33.33) | 3.90 (38.39) (28.29) |
| Dimethoate + *C. procera* | 6.63 (10.13) | 5.27 (20.51) (8.21) | 4.53 (31.67) (37.27) | 4.03 (39.22) (32.57) |
| *C. procera* + Neem Seed Powder | 6.77 (12.45) | 5.70 (15.81) (17.04) | 4.80 (29.10) (45.45) | 4.33 (36.04) (42.43) |
| Dimethoate + Neem Seed Powder | 6.70 (11.29) | 5.63 (15.97) (15.61) | 4.63 (30.90) (40.30) | 4.23 (36.87) (39.14) |
| Dimethoate + Neem Seed Powder + *C. procera* | 6.83 (13.45) | 5.80 (15.08) (19.10) | 4.97 (27.23) (50.61) | 4.87 (28.70) (60.20) |
| CD $P \leq 0.05$ | 0.47 | 0.23 | 0.66 | 0.94 |
| $P \leq 0.01$ | 0.66 | 0.33 | 0.94 | 1.33 |
| *F*- value | 6.60 | 36.80 | 9.41 | 0.05 |

| | | |
|---|---|---|
| Control Treatments (df = 7) | : | 6.6 |
| Fungus (df = 1) | : | 200.26 |
| Nematode (df = 1) | : | 36.8 |
| Treatments x Fungus (df = 7) | : | 0.53 |
| Treatments x Nematode (df = 7) | : | 9.41 |
| Fungus x nematodes (df = 1) | : | 0.09 |
| Treatments x Fungus x Nematode (df = 7) | : | 0.05 |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 24. Effect of seed treatment with different materials on root nodulation in pigeonpea inoculated with *Fusarium udum and Meloidogyne incognita,* singly and concomitantly under pot culture condition

| Treatment | Control | *Fusarium udum* (colonized seeds 2g/kg soil) | *Meloidogyne incognita* (2000 $J_2$/kg soil) | *F. dum + M. incognita* |
|---|---|---|---|---|
| Control | 42.3 | 38.0 (10.2) | 34.3 (18.9) | 29.3 (30.7) |
| Dimethoate | 43.0<br>(1.6) | 38.0 (11.6)<br>0.0 | 36.0 (16.2)<br>(4.9) | 32.0 (25.5)<br>(9.1) |
| *Calotropis procera* (latex) | $44.0^{a}$<br>(3.9) | $39.0^{a}$ (11.3)<br>(2.6) | $37.0^{a}$ (15.9)<br>(7.8) | 32.0 (27.2)<br>(9.1) |
| Neem Seed Powder | 43.0<br>(1.6) | $39.0^{a}$(9.3)<br>(2.6) | $37.0^{a}$ (13.9)<br>(7.8) | $33.0^{a}$ (23.2)<br>(12.5) |
| Dimethoate + *C. procera* | $44.0^{a}$<br>(3.9) | $40.0^{ab}$ (9.0)<br>(5.3) | $38.0^{ab}$ (13.6)<br>(10.7) | $35.0^{ab}$ (20.4)<br>(19.3) |
| *C. procera* + Neem Seed Powder | $45.0^{ab}$<br>(6.3) | $42.0^{ab}$ (6.6)<br>(10.5) | $42.0^{ab}$ (6.6)<br>(22.3) | $39.0^{ab}$ (13.3)<br>(33.0) |
| Dimethoate + Neem Seed Powder | $44.0^{a}$<br>(3.9) | $40.0^{ab}$ (9.0)<br>(5.3) | $39.0^{ab}$ (11.3)<br>(13.6) | $36.0^{ab}$ (18.1)<br>(22.7) |
| Dimethoate + Neem Seed Powder + *C. procera* | $45.0^{ab}$<br>(6.3) | $43.0^{ab}$ (4.4)<br>(13.2) | $43.0^{ab}$ (4.4)<br>(25.3) | $41.0^{ab}$ (8.8)<br>(39.8) |
| CD $P \leq 0.05$<br>$P \leq 0.01$ | 1.5<br>2.2 | 0.8<br>1.1 | 2.2<br>3.1 | 3.1<br>4.4 |
| *F*- value | : | | | |
| Control Treatments (df = 7) | : | $18.0^{cd}$ | | |
| Fungus (df = 1) | : | $91.0^{cd}$ | | |
| Nematode (df = 1) | : | $183.4^{cd}$ | | |
| Treatments x Fungus (df = 7) | : | NS | | |
| Treatments x Nematode (df = 7) | : | NS | | |
| Fungus x nematodes (df = 1) | : | NS | | |
| Treatments x Fungus x Nematode (df = 7) | : | $7.8^{c}$ | | |

Figures in parenthesis are percent increase or decrease over respective control; Significantly different from control at $P \leq 0.05^{a}$ and $P \leq 0.01^{b}$ Significant at $P \leq 0.05^{c}$ and $P \leq 0.01^{d}$; NS= Not significant at $P \leq 0.05$

Functional root nodules of plants increased in all the treatments from their respective control. Plant grown from the seeds treated with Dimethonate + Neem seed powder + *C. procera* showed 34.5, 39.3 and 94.7% ($P \leq 0.01$) increase in functional root nodules in *F. udum*, *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds (Table 25). Functional root nodules decreased 23.6 and 26.3% in the plants grown in *F. udum* and *M. incognita* inoculated soil, respectively. When both the pathogens were used simultaneously the decrease in functional root nodules was 50% as compared to uninoculated control. The decrease ($P \leq 0.01$) in functional nodules were least (11.9%) in plants grown from seeds treated with Dimethoate + Neem seed powder + *C. procera* followed by Dimethoate + Neem seed powder (17.5%) and *C. procera* + Neem seed powder (19.5) when soil was inoculated with both the pathogens *F. udum* and *M. incognita* concomitantly.

Non functional root nodules were higher in plants grown from untreated seeds in the soil treated with *F. udum* (68.8%) followed by *M. incognita* (18.7%), however it was highest (93.8%) as compared to control when both the pathogens were used simultaneously (Table 26). The lowest increase ($P \leq 0.01$) in non functional root nodules were found in plants grown in *F. udum* + *M. incognita* inoculated soil from the seeds treated with Dimethoate + Neem seed powder + *C. procera* followed by Dimethoate + Neem seed powder. As compared to the plants grown from untreated seeds non functional nodules decreased by 55.6, 52.6 and 51.6% ($P \leq 0.01$) in plant grown from the seeds treated with Dimethoate + Neem seed powder + *C. procera* in the soil inoculated with *F. udum*, *M. incognita* and *F. udum* + *M. incognita*, respectively.

The next better combination for seed treatment was *C. procera* + Neem seed powder which resulted in 55.6, 21.0 and 41.9% ($P \leq 0.01$) decrease in non functional nodules of plant grown in the soil inoculated with *F. udum*, *M. incognita* and *F. udum* + *M. incognita* respectively. The least effective treatment was Dimethoate which resulted in 33.3, 5.2 and 12.9% decrease in non functional root nodules of plants grown in *F. udum*, *M. incognita* and *F. udum* + *M. incognita* inoculated soil, respectively.

### 4.4.5 Soil population of pathogens

In all the cases where seed treatment was done population of juveniles of *M. incognita* significantly decreased ($P \leq 0.01$) in soil inoculated with *M. incognita* alone and in combination with *F. udum* (Table 27).

Table 25. Integrated nematode management of wilt (*Fusarium udum*), root-knot (*Meloidogyne incognita*) and fungus-nematode disease complex (*F.udum* + *M.incognita*) on functional nodulation in pigeonpea under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 38.00 | 29 (23.68) | 28 (26.32) | 19 (50.00) |
| *Dimethoate* | 38.00<br>0.00 | 32 15.79)<br>(10.34) | 30 (21.05)<br>(7.14) | 25 (34.21)<br>(31.58) |
| *Calotropis procera* | 39.00<br>(2.63) | 33 (15.38)<br>(13.79) | 31 (20.51)<br>(10.71) | 26 (33.33)<br>(36.84) |
| Neem Seed Powder | 39.00<br>(2.63) | 33 (15.38)<br>(13.79) | 32 (17.95)<br>(14.29) | 29 (25.64)<br>(52.63) |
| Dimethoate + *C. procera* | 40.00<br>(5.26) | 35 (12.50)<br>(20.69) | 33 (17.50)<br>(17.86) | 32 (20.00)<br>(68.42) |
| *C. procera* + Neem Seed Powder | 41.00<br>(7.89) | 38 (7.32)<br>(31) | 37 (9.76)<br>(32.14) | 33 (19.51)<br>(73.68) |
| *Dimethoate* + Neem Seed Powder | 40.00<br>(5.26) | 35 (12.50)<br>(20.69) | 34 (15.00)<br>(21.43) | 33 (17.50)<br>(73.68) |
| Dimethoate + Neem Seed Powder + *C. procera* | 42.00<br>(10.52) | 39 (7.14)<br>(34.48) | 39 (7.14)<br>(39.29) | 37 (11.90)<br>(94.74) |
| CD $P \leq 0.05$ | 2.53 | 1.26 | 3.58 | 5.06 |
| $P \leq 0.01$ | 3.56 | 1.78 | 5.03 | 7.12 |
| *F*- value | 14.30 | 82.57 | 1.34 | 0.25 |
| Control Treatments (df = 7) | : 14.3 | | | |
| Fungus (df = 1) | : 51.17 | | | |
| Nematode (df = 1) | : 82.57 | | | |
| Treatments x Fungus (df = 7) | : 1.38 | | | |
| Treatments x Nematode (df = 7) | : 1.34 | | | |
| Fungus x nematodes (df = 1) | : 1.75 | | | |
| Treatments x Fungus x Nematode (df = 7) | : 0.25 | | | |

Figures in parenthesis are percentage decrease over control ; [a]Significantly different from control at $P \leq 0.05$ ; [b]Significantly different from control at $P \leq 0.01$
[c]Significant at $P \leq 0.05$ ; [d]Significant at $P \leq 0.01$ ; NS= Not significant at $P \leq 0.05$

Table 26. Integrated nematode management and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on non functional nodule in pigeonpea under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 5.33 | 9.00 (68.86) | 6.33 (18.76) | 10.33 (93.81) |
| Dimethoate | 5.00 (6.20) | 6 (20.00) (33.33) | 6 (20.00) (5.21) | 9 (80.00) (12.88) |
| *Calotropis procera* | 5.00 (6.20) | 6 (20.00) (33.33) | 6 (20.00) (5.21) | 9 (80.00) (12.88) |
| Neem Seed Powder | 4.00 (24.95) | 6 (50.00) (33.33) | 5 (25.00) (21.01) | 8 (100.00) (22.56) |
| Dimethoate + *C. procera* | 4.00 (24.95) | 5 (25.00) (44.44) | 5 (25.00) (21.01) | 6 (50.00) (41.92) |
| *C. procera* + Neem Seed Powder | 4.00 (24.95) | 4 (0.00) (55.56) | 5 (25.00) (21.01) | 6 (50.00) (41.92) |
| Dimethoate + Neem Seed Powder | 4.00 (24.95) | 5 (25.00) (44.44) | 5 (25.00) (21.01) | 6 (50.00) (41.92) |
| Dimethoate + Neem Seed Powder + *C. procera* | 3.00 (43.72) | 4 (33.33) (55.56) | 3 (0.00) (52.61) | 5 (66.67) (51.60) |
| CD $P \leq 0.05$ | 2.34 | 1.17 | 3.31 | 4.68 |
| $P \leq 0.01$ | 3.29 | 1.64 | 4.65 | 6.58 |
| *F*- value | 2.10 | 4.98 | 0.48 | 0.05 |

| | | |
|---|---|---|
| Control Treatments (df = 7) | : | 2.1 |
| Fungus (df = 1) | : | 9 |
| Nematode (df = 1) | : | 4.98 |
| Treatments x Fungus (df = 7) | : | 0.38 |
| Treatments x Nematode (df = 7) | : | 0.48 |
| Fungus x nematodes (df = 1) | : | 0.09 |
| Treatments x Fungus x Nematode (df = 7) | : | 0.05 |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 27. Integrated nematode management in pigeonpea and effect of inoculation with *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on nematode population in soil under pot culture condition

| Treatments | Control | *Fusarium udum* (2g/kg soil) | *Meloidogyne incognita* (2000 J2/kg soil) | *Fusarium udum* + *Meloidogyne incognita* |
|---|---|---|---|---|
| Control | 0.00 | 0.00 | 3316.00 | 2922.00 (11.88) |
| Dimethoate | 0.00 | 0.00 | 3022.67 (8.85) | 2516.67 (16.74) (13.87) |
| *Calotropis procera* | 0.00 | 0.00 | 2848.67 (14.09) | 2300.00 (19.26) (21.29) |
| Neem Seed Powder | 0.00 | 0.00 | 2581.67 (22.15) | 2090.00 (19.04) (28.47) |
| Dimethoate + *C. procera* | 0.00 | 0.00 | 2393.33 (27.82) | 1968.00 (17.77) (32.65) |
| *C. procera* + Neem Seed Powder | 0.00 | 0.00 | 1861.67 (43.86) | 1540.33 (17.26) (47.29) |
| Dimethoate + Neem Seed Powder | 0.00 | 0.00 | 2228.33 (32.80) | 1821.33 (18.26) (37.67) |
| Dimethoate + Neem Seed Powder + *C. procera* | 0.00 | 0.00 | 1605.00 (51.60) | 939.00 (41.50) (67.86) |
| CD $P \leq 0.05$ | | | 187.82 | 265.62 |
| $P \leq 0.01$ | | | 264.10 | 373.50 |
| *F*- value | | | 39.96 | 0.89 |

| | | |
|---|---|---|
| Control Treatments (df = 7) | : | 33.98 |
| Fungus (df = 1) | : | 39.96 |
| Nematode (df = 1) | : | 4317.9 |
| Treatments x Fungus (df = 7) | : | 0.89 |
| Treatments x Nematode (df = 7) | : | 39.96 |
| Fungus x nematodes (df = 1) | : | 33.98 |
| Treatments x Fungus x Nematode (df = 7) | : | 0.89 |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

A reduction in soil population of juveniles *M. incognita* was observed of when both the pathogens *M. incognita* and *F. udum* was simultaneously applied in soil than either of the pathogen alone. A significant reduction ($P \leq 0.01$) in juvenile population of *M. incognita* was observed in soil where seeds were treated with a combination of Dimethoate + Neem seed powder + *C. procera* followed by *C. procera* + Neem seed powder. The least effective treatment was Dimethoate which resulted in 8.9 and 13.9% decrease in soil population of juveniles of *M. incognita* in the soil inoculated with *M. incognita* and *F. udum* + *M. incognita*, respectively.

The soil population of *F. udum* increased during the cropping season but gradually decreased at harvesting period in case of untreated seeds (Table 28). In presence of *M. incognita* population of *F. udum* increased in soil than *F.udum* alone. In all cases where seed treatment was done population of wilt fungus, *F. udum* decreased in soil during cropping and harvesting time over initial population. The maximum suppression of wilt fungus *F. udum* in soil was found where seed treatment was done with a combination of Dimethoate + Neem seed powder + *C. procera.* In this combination the population of *F. udum* was found 13.6 x $10^7$ and 14.2 x $10^7$ $CFU_s$ /g in *F. udum* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to initial population of 2 x $10^8$ during the mid season of cropping (Table 8). At harvest the soil population of *F. udum* during the same combination of seed treatment decreased to 11.4 x $10^7$ and 12.2 x $10^7$ $CFU_s$/g in *F. udum* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to initial inoculum level of 2 x $10^8$. Seeds treated with a combination of Dimethoate + Neem seed powder + *C. procera* resulted in a decrease of 99.5 and 99.68% soil population of *F. udum* in case of *F. udum* and *F. udum* + *M. incognita* inoculated soil, respectively as compared to untreated seeds.

Table 28. Rhizoshpere population (CFUs) of *Fusarium udum* in soil

| Treatment | At sowing | | Mid season | | Harvesting | |
|---|---|---|---|---|---|---|
| | fu | fu+mi | fu | fu+mi | fu | fu+mi |
| Control | $2x10^8$ | $2x10^8$ | $3.0 x10^{10}$ | $4.5 x10^{10}$ | $2.5 x10^8$ | 2.80X10 |
| | | | **15** | | | |
| Dimethoate | $2x10^8$ | $2x10^8$ | $2.8 x10^{10}$ | $4.3 x10^{10}$ | $2.5 x10^8$ | $2.6 x10^8$ |
| | | | **(4)** | **(3)** | **(6)** | **(5)** |
| *C. procera*(latex) | $2x10^8$ | $2x10^8$ | $2.6 x10^{10}$ | $4.0 x10^{10}$ | $2.1 x10^8$ | $2.3 x10^8$ |
| | | | **(11)** | **(10)** | **(16)** | **(16)** |
| Neem seed Powder | $2x10^8$ | $2x10^8$ | $2.4 x10^{10}$ | $3.7 x10^{10}$ | $1.8 x10^8$ | $2.1 x10^8$ |
| | | | **(18)** | **(16)** | **(25)** | **(24)** |
| Dimethoate + *C.* | $2x10^8$ | $2x10^8$ | $2.6 x10^{10}$ | $4.0 x10^{10}$ | $2.0 x10^8$ | $2.3 x10^8$ |
| | | | **(13)** | **(11)** | **(19)** | **(17)** |
| *C. procera*+ NSP | $2x10^8$ | $2x10^8$ | $2.2 x10^{10}$ | $3.4 x10^{10}$ | $1.6 x10^8$ | $1.9 x10^8$ |
| | | | **(25)** | **(23)** | **(34)** | **(30)** |
| Dimethoate + NSP | $2x10^8$ | $2x10^8$ | $2.4 x10^{10}$ | $3.6 x10^{10}$ | $1.8 x10^8$ | $2.1 x10^8$ |
| | | | **(19)** | **(18)** | **(27)** | **(25)** |
| Dimethoate + NSP + *C.* | $2x10^8$ | $2x10^8$ | $2.0 x10^{10}$ | $3.2 x10^{10}$ | $1.4 x10^8$ | $1.7 x10^8$ |
| | | | **(32)** | **(29)** | **(43)** | **(39)** |

Figures in parenthesis are percentage increase over initial population.

## Experiment 3

### 4.5 Field trial

### 4.5.1 To study the single and interactive pathogenic effects of root-knot nematode *Meloidogyne incognita* and wilt fungus *Fusarium udum* on pigeonpea germplasm under pot and field condition.

Interaction of *M. incognita* and *F. udum* was investigated on 25 cultivars of pigeonpea in 4x2m microplots under field. Inoculation with the pathogens was done by applying 2g fungus colonized seeds/kg soil and 2000 juveniles of *M. incognita*/kg soil singly and concomitantly.

### 4.6 Symptoms

### 4.6.1 Fusarial wilt

Plants grown in plots inoculated with sorghum seeds colonized by *F. udum* showed wilt symptoms. The first sign of the disease was mild chlorosis and stunted growth that appeared at seedling stage. The cultivar found most susceptible to *F. udum* was Bahar which developed 38% wilt incidence followed by CO-6 (25%) and GAUT 001E (24.4%) (Table 29). The cvs. ICP8863, ICPL 89048 and ICP 14722 expressed tolerance and developed 3.2-3.4% incidence. Plants grown in plots inoculated with *F. udum* and *M. incognita* concomitantly exhibited greater stunting of plants chlorosis and drying of leaves. Wilt incidence was significantly greater ($P \leq 0.01$) compared to the wilting recorded in the plots inoculated with *F. udum* alone (Table 29 and 30). Highest wilt incidence in the fungus-nematode infested plots was recorded in Bahar (57.6%) followed by CO-6 (36.2%) and GAUT 001E (34.8%). The cvs. ICP 8863, ICPL87119 and ICPL89048 developed 14.1, 27.9 and 20% wilt incidence respectively in the presence of nematode, whereas the incidence was 3.2-3.4% in the absence of nematode.

### 4.6.2 Root-knot

Plants grown in nematode infested soil also showed stunted growth and dull green foliage. On the roots of plants uprooted at maturity numerous galls were observed. Greatest number of galls were recorded on the cv. CO-6 (53) followed by Pusa 855 (50) (Table 31). The gall count /root system was lowest in AKT 8811 (15), ICP 8863 and AWR 74/15 (16). Egg masses were recorded on the galls and their count was highest on the cvs. ICP 8863 and AWR 74/15 (9 each). The plants grown in the wilt fungus and root-knot nematode infested soil, the gall formation and egg mass production were significantly lower ($P \leq 0.01$) on all the cultivars tested in comparison to the absence of the fungus.

Table 29. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on wilt incidence in pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 0.00 | 18.82 | 0.00 | 26.50 (40.81) | 2.24 | 3.38 | 431.68 |
| Manak | 0.00 | 11.36 | 0.00 | 17.04 (50.00) | 1.58 | 2.38 | 348.68 |
| ICPL 87 | 0.00 | 22.22 | 0.00 | 30.76 (38.43) | 2.50 | 3.78 | 469.94 |
| ICP 14722 | 0.00 | 3.44 | 0.00 | 26.31 (664.83) | 2.08 | 3.14 | 444.79 |
| AL 201 | 0.00 | 23.91 | 0.00 | 34.04 (42.37) | 3.05 | 4.60 | 382.11 |
| C11 | 0.00 | 23.65 | 0.00 | 31.86 (34.71) | 1.30 | 1.96 | 1899.47 |
| Sarvodaya | 0.00 | 11.11 | 0.00 | 16.18 (45.63) | 2.07 | 3.12 | 185.39 |
| ICP 8859 | 0.00 | 4.83 | 0.00 | 21.31 (341.20) | 3.01 | 4.55 | 134.55 |
| ICPL 89049 | 0.00 | 4.91 | 0.00 | 28.33 (476.99) | 2.36 | 3.57 | 393.30 |
| DPPA 85-13 | 0.00 | 4.76 | 0.00 | 15.62 (228.15) | 1.66 | 2.50 | 236.06 |
| ICPL 89048 | 0.00 | 3.33 | 0.00 | 27.86 (736.64) | 3.02 | 3.56 | 237.76 |
| ICPL 87119 | 0.00 | 3.38 | 0.00 | 20.00 (491.72) | 2.19 | 3.31 | 227.60 |
| AKT 8811 | 0.00 | 9.67 | 0.00 | 14.30 (47.88) | 2.60 | 3.85 | 94.24 |
| CO-6 | 0.00 | 25.00 | 0.00 | 36.17 (44.68) | 0.72 | 1.08 | 7704.24 |
| GAUT 001E | 0.00 | 24.44 | 0.00 | 34.78 (42.31) | 2.00 | 3.03 | 921.21 |
| GT 100 | 0.00 | 16.30 | 0.00 | 21.50 (31.90) | 1.59 | 2.40 | 585.49 |
| Pusa 84 | 0.00 | 15.55 | 0.00 | 19.78 (27.20) | 1.74 | 2.62 | 423.71 |
| AWR 74/15 | 0.00 | 4.83 | 0.00 | 14.28 (195.65) | 1.54 | 2.33 | 227.46 |
| ICP 8863 | 0.00 | 3.17 | 0.00 | 14.06 (343.53) | 1.21 | 1.83 | 363.30 |
| AL 15 | 0.00 | 21.97 | 0.00 | 29.34 (33.55) | 3.02 | 4.56 | 299.07 |
| Pusa 855 | 0.00 | 24.73 | 0.00 | 35.10 (41.93) | 2.72 | 4.10 | 512.18 |
| Bahar | 0.00 | 22.58 | 0.00 | 34.92 (54.65) | 3.76 | 5.68 | 254.29 |
| GCP 33 | 0.00 | 4.83 | 0.00 | 26.98 (458.59) | 1.98 | 2.99 | 506.15 |
| Pusa 33 | 0.00 | 19.56 | 0.00 | 26.88 (37.42) | 3.11 | 4.70 | 232.44 |
| Paras | 0.00 | 21.11 | 0.00 | 27.47 (30.13) | 3.13 | 4.73 | 247.58 |
| CD $P \leq 0.05$ $P \leq 0.01$ | | 6.48 10.04 | | 5.94 9.96 | | | |
| *F*-value | | 1.58 | | 1.15 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 30. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on wilt severity in pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 0.00 | 22.10 | 0.00 | 32.60 (47.51) | 1.79 | 2.71 | 992.42 |
| Manak | 0.00 | 12.30 | 0.00 | 21.30 (73.17) | 3.21 | 4.84 | 124.97 |
| ICPL 87 | 0.00 | 28.30 | 0.00 | 37.10 (31.10) | 2.01 | 3.03 | 1093.51 |
| ICP 14722 | 0.00 | 9.00 | 0.00 | 24.40 (171.11) | 1.82 | 2.75 | 478.88 |
| AL 201 | 0.00 | 30.30 | 0.00 | 39.10 (29.04) | 1.33 | 2.01 | 2801.22 |
| C11 | 0.00 | 28.50 | 0.00 | 37.30 (30.88) | 1.79 | 2.71 | 1385.68 |
| Sarvodaya | 0.00 | 11.20 | 0.00 | 20.10 (79.46) | 1.97 | 2.97 | 293.33 |
| ICP 8859 | 0.00 | 8.50 | 0.00 | 22.40 (163.53) | 2.04 | 3.08 | 321.63 |
| ICPL 89049 | 0.00 | 9.50 | 0.00 | 25.40 (167.37) | 1.63 | 2.47 | 643.11 |
| DPPA 85-13 | 0.00 | 8.20 | 0.00 | 18.30 (123.17) | 1.04 | 1.57 | 839.17 |
| ICPL 89048 | 0.00 | 9.20 | 0.00 | 25.10 (172.83) | 1.54 | 2.32 | 708.79 |
| ICPL 87119 | 0.00 | 8.50 | 0.00 | 21.80 (156.47) | 1.15 | 1.73 | 963.55 |
| AKT 8811 | 0.00 | 7.50 | 0.00 | 16.70 (122.67) | 1.10 | 1.66 | 623.88 |
| CO-6 | 0.00 | 31.40 | 0.00 | 41.50 (32.17) | 1.06 | 1.60 | 4888.30 |
| GAUT 001E | 0.00 | 30.60 | 0.00 | 40.30 (31.70) | 1.25 | 1.89 | 3312.75 |
| GT 100 | 0.00 | 19.30 | 0.00 | 27.80 (44.04) | 2.57 | 3.89 | 355.17 |
| Pusa 84 | 0.00 | 14.40 | 0.00 | 21.40 (48.61) | 1.70 | 2.57 | 472.45 |
| AWR 74/15 | 0.00 | 7.80 | 0.00 | 17.60 (125.64) | 0.66 | 1.00 | 1903.60 |
| ICP 8863 | 0.00 | 7.50 | 0.00 | 17.00 (126.67) | 1.70 | 2.57 | 267.38 |
| AL 15 | 0.00 | 27.50 | 0.00 | 36.60 (33.09) | 0.87 | 1.31 | 5627.19 |
| Pusa 855 | 0.00 | 30.90 | 0.00 | 40.70 (31.72) | 1.09 | 1.64 | 4482.54 |
| Bahar | 0.00 | 32.00 | 0.00 | 45.80 (43.13) | 0.98 | 1.48 | 6695.25 |
| GCP 33 | 0.00 | 9.00 | 0.00 | 24.20 (168.89) | 1.26 | 1.90 | 987.99 |
| Pusa 33 | 0.00 | 20.70 | 0.00 | 35.10 (69.57) | 6.46 | 9.76 | 84.07 |
| Paras | 0.00 | 26.10 | 0.00 | 36.40 (39.46) | 1.20 | 1.81 | 2860.78 |
| CD $P \leq 0.05$ $P \leq 0.01$ | | 7.41 10.89 | | 6.86 9.94 | | | |
| *F*-value | | 1.50 | | 1.59 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 31. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the root galls in pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 0.00 | 0.00 | 33.00 | 22.00 (33.33) | 4.89 | 7.38 | 136.13 |
| Manak | 0.00 | 0.00 | 23.00 | 18.00 (21.74) | 3.46 | 5.22 | 144.25 |
| ICPL 87 | 0.00 | 0.00 | 43.00 | 32.00 (25.58) | 4.11 | 6.21 | 345.12 |
| ICP 14722 | 0.00 | 0.00 | 33.00 | 23.00 (30.30) | 3.78 | 5.70 | 232.74 |
| AL 201 | 0.00 | 0.00 | 47.00 | 36.00 (23.40) | 4.89 | 7.38 | 297.13 |
| C11 | 0.00 | 0.00 | 46.00 | 35.00 (23.91) | 6.52 | 9.84 | 159.45 |
| Sarvodaya | 0.00 | 0.00 | 20.00 | 17.00 (15.00) | 4.75 | 7.17 | 61.19 |
| ICP 8859 | 0.00 | 0.00 | 29.00 | 20.00 (31.03) | 3.78 | 5.70 | 178.81 |
| ICPL 89049 | 0.00 | 0.00 | 40.00 | 30.00 (25.00) | 4.61 | 6.96 | 239.06 |
| DPPA 85-13 | 0.00 | 0.00 | 18.00 | 15.00 (16.67) | 5.25 | 7.93 | 40.01 |
| ICPL 89048 | 0.00 | 0.00 | 37.00 | 27.00 (27.03) | 2.99 | 4.52 | 477.33 |
| ICPL 87119 | 0.00 | 0.00 | 27.00 | 19.00 (29.63) | 2.99 | 4.52 | 249.33 |
| AKT 8811 | 0.00 | 0.00 | 15.00 | 13.00 (13.33) | 1.90 | 2.80 | 216.00 |
| CO-6 | 0.00 | 0.00 | 53.00 | 39.00 (26.42) | 3.82 | 5.77 | 603.82 |
| GAUT 001E | 0.00 | 0.00 | 45.00 | 38.00 (15.56) | 2.30 | 3.48 | 1310.06 |
| GT 100 | 0.00 | 0.00 | 30.00 | 20.00 (33.33) | 4.11 | 6.21 | 158.82 |
| Pusa 84 | 0.00 | 0.00 | 27.00 | 20.00 (25.93) | 1.91 | 2.89 | 618.18 |
| AWR 74/15 | 0.00 | 0.00 | 16.00 | 13.00 (18.75) | 3.46 | 5.22 | 71.58 |
| ICP 8863 | 0.00 | 0.00 | 16.00 | 14.00 (12.50) | 2.99 | 4.52 | 100.89 |
| AL 15 | 0.00 | 0.00 | 41.00 | 32.00 (21.95) | 3.46 | 5.22 | 457.58 |
| Pusa 855 | 0.00 | 0.00 | 50.00 | 39.00 (22.00) | 1.91 | 2.89 | 2226.27 |
| Bahar | 0.00 | 0.00 | 33.00 | 20.00 (39.39) | 2.99 | 4.52 | 349.67 |
| GCP 33 | 0.00 | 0.00 | 31.00 | 22.00 (29.03) | 3.46 | 5.22 | 247.58 |
| Pusa 33 | 0.00 | 0.00 | 33.00 | 25.00 (24.24) | 4.89 | 7.38 | 145.50 |
| Paras | 0.00 | 0.00 | 34.00 | 26.00 (23.53) | 4.42 | 6.68 | 189.56 |
| CD $P \leq 0.05$ $P \leq 0.01$ | | | 7.47 11.03 | 9.72 13.54 | | | |
| *F*-value | | | 0.71 | 0.76 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Greatest egg mass per root system recorded on the cvs. CO-6 and Pusa 855 in the presence of the wilt fungus were 31 whereas in the absence of the fungus it was 51 and 48, respectively (Table 32).

### 4.6.3 Plant growth and yield

Inoculation with *F. udum* suppressed dry weight of plants up to 17% ($P \leq 0.01$) over control (Table 33). Greatest reduction in dry weight due to the wilt fungus was observed in the cv. CO-6 (17%) whereas it was lowest in ICP 8863 (0.3%) (Table 33). Decrease in the yield was highest in the cv. Bahar (23.2%) and lowest in ICP 8863 (0.3%) (Table 34). The cvs. DPPA 85-13, ICPL 87119, AWR 74/15, ICP 8863 exhibited less than 3% decrease in the yield due to the fungus inoculation over control (Table 34). Inoculation with *M. incognita* suppressed the dry matter production, being significant in the cvs. ICPL 87, ICP 14722, AL201, C11, Sarvodaya, ICP8859, ICPL 89049, DPPA 85-13, ICPL 89048, ICPL 87119, AKT 8811, CO-6, GT 100, AWR 74/15, Pusa 855, GCP 33, Paras ($P \leq 0.01$) and UPAS 120, Manak, GAUT 001, ICP 8863, Bahar and Pusa 33 ($P \leq 0.05$) over control. Nematode inoculation decreased the yield in the cvs. ICPL 87, ICP 14722, C11, ICP 8859, ICPl89049, ICPL 87119, AKT 8811, CO-6, AL 15, Bahar, GCP 33., Paras ($P \leq 0.01$) and AL201, Sarvodaya, DPPA 85-13, GAUT 001E, Pusa 84, AWR 74/15, ICP 8863, Pusa 855 and Pusa 33 ($P \leq 0.05$). The cv.AL 15 did not exhibit decrease in the plant growth and cv. UPAS 120 and Manak did not exhibit decrease in yield due to the inoculation with the nematode. Concomitant inoculations with *F. udum* and *M. incognita* caused significantly greater decline ($P \leq 0.05$ or 0.01) in dry matter and yield in all pigeonpea cultivars in comparison to the reduction caused by either pathogens. Greatest decrease in dry weight was observed in CO-6 (26.6%) whereas it was lowest in ICP 8863 (7.4%). Yield reduction was highest in CO-6 (37.7%) and lowest in ICP 8863 (13.8%). In all the cultivars the reduction caused by the fungus and nematode together was significantly ($P \leq 0.01$) greater than sum of the reductions caused by the two pathogens individually (Table 34).

### 4.6.4 Root nodulation

Plants grown in microplots not inoculated with any pathogen showed good root nodulation (Table 35). Infection by *F. udum* decreased the functional nodules by upto 22% and increased non functional nodules upto 44.4% in different cultivars of pigeonpea tested (Table 36 and 37). Significant decrease in the functional nodules occurred in cvs. Manak, AKT 8811, GAUT 001e, ICP 8863, Pusa 855, Bahar, GCP 33, Pusa 33 ($P \leq 0.01$) and AL

Table 32. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the egg mass per root system in pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 0.00 | 0.00 | 27.00 | 13.00 (51.85) | 1.91 | 2.89 | 543.27 |
| Manak | 0.00 | 0.00 | 17.00 | 9.00 (47.06) | 2.82 | 4.26 | 100.50 |
| ICPL 87 | 0.00 | 0.00 | 40.00 | 26.00 (35.00) | 2.99 | 4.52 | 527.56 |
| ICP 14722 | 0.00 | 0.00 | 27.00 | 16.00 (40.74) | 3.82 | 5.77 | 142.57 |
| AL 201 | 0.00 | 0.00 | 43.00 | 29.00 (32.56) | 2.51 | 3.79 | 880.42 |
| C11 | 0.00 | 0.00 | 43.00 | 28.00 (34.88) | 4.71 | 7.12 | 245.87 |
| Sarvodaya | 0.00 | 0.00 | 14.00 | 8.00 (42.86) | 2.30 | 3.48 | 104.25 |
| ICP 8859 | 0.00 | 0.00 | 23.00 | 12.00 (47.83) | 2.51 | 3.79 | 231.63 |
| ICPL 89049 | 0.00 | 0.00 | 35.00 | 21.00 (40.00) | 2.51 | 3.79 | 557.05 |
| DPPA 85-13 | 0.00 | 0.00 | 11.00 | 8.00 (27.27) | 2.51 | 3.79 | 59.84 |
| ICPL 89048 | 0.00 | 0.00 | 31.00 | 19.00 (38.71) | 4.89 | 7.38 | 116.17 |
| ICPL 87119 | 0.00 | 0.00 | 20.00 | 11.00 (45.00) | 3.82 | 5.77 | 76.57 |
| AKT 8811 | 0.00 | 0.00 | 8.00 | 7.00 (12.50) | 2.51 | 3.79 | 35.84 |
| CO-6 | 0.00 | 0.00 | 51.00 | 31.00 (39.22) | 2.90 | 4.50 | 836.00 |
| GAUT 001E | 0.00 | 0.00 | 44.00 | 30.00 (31.82) | 4.11 | 6.21 | 345.18 |
| GT 100 | 0.00 | 0.00 | 25.00 | 12.00 (52.00) | 4.89 | 7.38 | 71.13 |
| Pusa 84 | 0.00 | 0.00 | 19.00 | 12.00 (36.84) | 2.51 | 3.79 | 167.21 |
| AWR 74/15 | 0.00 | 0.00 | 9.00 | 8.00 (11.11) | 1.91 | 2.89 | 79.36 |
| ICP 8863 | 0.00 | 0.00 | 9.00 | 7.00 (22.22) | 1.90 | 2.80 | 72.00 |
| AL 15 | 0.00 | 0.00 | 37.00 | 22.00 (40.54) | 5.02 | 7.58 | 155.17 |
| Pusa 855 | 0.00 | 0.00 | 48.00 | 31.00 (35.42) | 2.82 | 4.26 | 852.38 |
| Bahar | 0.00 | 0.00 | 29.00 | 14.00 (51.72) | 3.78 | 5.70 | 160.40 |
| GCP 33 | 0.00 | 0.00 | 25.00 | 13.00 (48.00) | 4.11 | 6.21 | 101.88 |
| Pusa 33 | 0.00 | 0.00 | 28.00 | 18.00 (35.71) | 5.02 | 7.58 | 91.42 |
| Paras | 0.00 | 0.00 | 30.00 | 18.00 (40.00) | 2.99 | 4.52 | 288.00 |
| CD $P \leq 0.05$ $P \leq 0.01$ | | | 10.55 15.21 | 7.12 10.33 | | | |
| *F*-value | | | 0.96 | 0.81 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 33. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the dry weight of pigeonpea plants under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 10.68 | 9.90 (7.30) | 9.42 (11.80) | 8.76 (17.98) | 1.25 | 1.88 | 5.03 |
| Manak | 10.98 | 10.32 (6.01) | 10.02 (8.74) | 9.42 (14.21) | 0.72 | 1.09 | 9.64 |
| ICPL 87 | 10.56 | 9.78 (7.39) | 9.60 (9.09) | 8.70 (17.61) | 0.66 | 1.00 | 15.77 |
| ICP 14722 | 18.84 | 18.35 (2.60) | 18.00 (4.46) | 17.22 (8.60) | 0.34 | 0.51 | 48.72 |
| AL 201 | 9.96 | 9.06 (17.34) | 8.82 (19.53) | 8.04 (26.64) | 0.48 | 0.73 | 32.35 |
| C11 | 10.20 | 9.30 (8.82) | 9.24 (9.41) | 8.70 (14.71) | 0.43 | 0.65 | 24.97 |
| Sarvodaya | 10.92 | 10.20 (6.59) | 9.90 (9.34) | 9.24 (15.38) | 0.55 | 0.83 | 19.12 |
| ICP 8859 | 19.38 | 19.08 (1.55) | 18.12 (6.50) | 17.70 (8.67) | 0.84 | 1.27 | 10.50 |
| ICPL 89049 | 19.20 | 18.60 (4.62) | 17.82 (8.62) | 17.28 (11.38) | 0.85 | 1.28 | 11.85 |
| DPPA 85-13 | 18.60 | 18.25 (1.88) | 17.46 (6.13) | 16.86 (9.35) | 0.31 | 0.47 | 75.38 |
| ICPL 89048 | 19.02 | 18.50 (2.73) | 17.88 (5.99) | 17.28 (9.15) | 0.37 | 0.56 | 50.04 |
| ICPL 87119 | 18.89 | 18.65 (1.27) | 18.00 (4.71) | 17.10 (9.48) | 0.52 | 0.79 | 28.38 |
| AKT 8811 | 10.56 | 10.40 (1.52) | 9.54 (9.66) | 9.00 (14.77) | 0.27 | 0.41 | 87.01 |
| CO-6 | 10.74 | 9.96 (7.26) | 9.84 (8.38) | 9.30 (13.41) | 0.29 | 0.44 | 49.68 |
| GAUT 001E | 11.40 | 10.68 (6.32) | 10.68 (6.32) | 10.08 (11.58) | 0.66 | 0.99 | 8.03 |
| GT 100 | 11.22 | 10.44 (6.95) | 10.32 (8.02) | 9.84 (12.30) | 0.50 | 0.75 | 15.69 |
| Pusa 84 | 11.52 | 10.80 (6.25) | 10.80 (6.25) | 10.14 (11.98) | 0.82 | 1.24 | 5.66 |
| AWR 74/15 | 18.60 | 18.30 (1.61) | 17.70 (4.84) | 17.22 (7.42) | 0.38 | 0.58 | 30.92 |
| ICP 8863 | 19.32 | 19.17 (0.26) | 18.42 (4.16) | 17.82 (7.28) | 0.77 | 1.16 | 9.81 |
| AL 15 | 10.80 | 10.02 (7.22) | 10.08 (6.67) | 9.42 (12.78) | 0.85 | 1.28 | 5.29 |
| Pusa 855 | 10.14 | 9.42 (7.10) | 9.18 (14.04) | 8.82 (17.42) | 0.59 | 0.89 | 1.07 |
| Bahar | 19.50 | 18.42 (5.54) | 18.60 (4.62) | 17.88 (8.31) | 0.76 | 1.14 | 9.47 |
| GCP 33 | 18.90 | 18.50 (2.12) | 17.70 (6.35) | 17.22 (8.89) | 0.77 | 1.17 | 11.58 |
| Pusa 33 | 10.38 | 9.60 (7.51) | 9.66 (6.94) | 9.00 (13.29) | 0.65 | 0.98 | 9.12 |
| Paras | 10.68 | 9.42 (11.80) | 9.30 (12.92) | 8.64 (19.10) | 0.90 | 1.35 | 10.80 |
| CD $P \leq 0.05$ | 3.15 | 3.27 | 3.16 | 3.14 | | | |
| $P \leq 0.01$ | 5.33 | 5.58 | 5.35 | 5.31 | | | |
| *F*-value | 1.52 | 1.52 | 1.44 | 1.49 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 34. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the yield of pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 1106.00 | 980.00 (11.39) | 972.00 (12.12) | 810.00 (26.76) | 151.70 | 229.12 | 7.64 |
| Manak | 1126.00 | 1020.00 (9.41) | 1005.00 (1075.00) | 900.00 (20.07) | 131.70 | 198.91 | 5.89 |
| ICPL 87 | 1041.00 | 880.00 (15.47) | 850.00 (18.35) | 730.00 (29.88) | 114.63 | 173.13 | 14.92 |
| ICP 14722 | 1740.00 | 1670.00 (4.02) | 1500.00 (13.79) | 1260.00 (27.59) | 134.92 | 203.77 | 29.93 |
| AL 201 | 845.00 | 700.00 (17.16) | 660.00 (21.89) | 570.00 (32.54) | 123.09 | 185.92 | 10.34 |
| C11 | 932.00 | 780.00 (16.31) | 740.00 (20.60) | 640.00 (31.33) | 101.68 | 153.57 | 16.98 |
| Sarvodaya | 1148.00 | 1050.00 (8.54) | 1030.00 (10.28) | 930.00 (18.99) | 109.25 | 165.01 | 7.99 |
| ICP 8859 | 1810.00 | 1750.00 (3.31) | 1600.00 (11.60) | 1395.00 (22.93) | 78.56 | 118.65 | 66.20 |
| ICPL 89049 | 1671.00 | 1590.00 (4.85) | 1400.00 (16.22) | 1190.00 (28.79) | 153.18 | 231.35 | 23.39 |
| DPPA 85-13 | 1836.00 | 1790.00 (2.51) | 1670.00 (9.04) | 1540.00 (16.12) | 113.22 | 171.00 | 16.39 |
| ICPL 89048 | 1936.00 | 1830.00 (5.48) | 1620.00 (16.32) | 1370.00 (29.24) | 119.89 | 181.07 | 51.91 |
| ICPL 87119 | 1723.00 | 1680.00 (2.50) | 1530.00 (11.20) | 1340.00 (22.23) | 62.52 | 94.42 | 91.67 |
| AKT 8811 | 1068.00 | 995.00 (6.84) | 990.00 (7.30) | 920.00 (13.86) | 45.18 | 68.23 | 21.39 |
| CO-6 | 770.00 | 600.00 (22.08) | 565.00 (26.62) | 480.00 (37.66) | 86.35 | 130.41 | 23.74 |
| GAUT 001E | 805.00 | 655.00 (18.63) | 638.00 (20.75) | 535.00 (33.54) | 134.12 | 202.57 | 8.22 |
| GT 100 | 1043.00 | 930.00 (10.83) | 920.00 (11.79) | 790.00 (24.26) | 127.33 | 192.31 | 7.89 |
| Pusa 84 | 1045.00 | 940.00 (10.05) | 930.00 (11.00) | 820.00 (21.53) | 103.79 | 156.76 | 9.37 |
| AWR 74/15 | 1763.00 | 1740.00 (1.30) | 1620.00 (8.11) | 1505.00 (14.63) | 107.85 | 162.90 | 14.58 |
| ICP 8863 | 1976.00 | 1970.00 (0.30) | 1830.00 (7.39) | 1700.00 (13.79) | 139.49 | 210.69 | 10.58 |
| AL 15 | 961.00 | 820.00 (14.67) | 790.00 (17.79) | 680.00 (29.24) | 107.57 | 162.47 | 13.82 |
| Pusa 855 | 830.00 | 670.00 (19.28) | 620.00 (25.30) | 538.00 (35.18) | 103.73 | 156.66 | 16.80 |
| Bahar | 1980.00 | 1520.00 (23.23) | 1640.00 (17.17) | 1340.00 (32.32) | 65.93 | 99.58 | 200.00 |
| GCP 33 | 1940.00 | 1870.00 (3.61) | 1700.00 (12.37) | 1415.00 (27.06) | 66.37 | 100.24 | 148.06 |
| Pusa 33 | 1036.00 | 900.00 (13.13) | 890.00 (14.09) | 750.00 (27.61) | 113.05 | 170.74 | 12.76 |
| Paras | 1023.00 | 875.00 (14.47) | 870.00 (14.96) | 735.00 (28.15) | 61.96 | 93.58 | 43.07 |
| CD $P \leq 0.05$ | 339.35 | 345.20 | 320.00 | 282.31 | | | |
| $P \leq 0.01$ | 462.31 | 514.06 | 513.40 | 437.62 | | | |
| *F*-value | 1.42 | 1.64 | 1.40 | 1.50 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 35. Effect of inoculations with *Fusarium udum* and *Meloidogyne incognita,* singly and concomitantly on root nodulation in pigeonpea under field condition

| Cultivar | Control | *Fusarium udum* $2x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 44.0 | 40.0 (9.1) | 40.0 (9.1) | $37.0^{ab}$ (15.9) | 4.1 | 6.2 | $5.8^{e}$ |
| Manak | 47.0 | $44.0^{ab}$ (6.4) | $43.0^{ab}$ (8.5) | $40.0^{ab}$ (14.9) | 1.6 | 2.5 | $37.5^{cd}$ |
| ICPL 87 | 42.0 | 38.0 (9.5) | $35.0^{ab}$ (16.7) | $33.0^{ab}$ (21.4) | 4.1 | 6.2 | $10.8^{cd}$ |
| ICP 14722 | 58.0 | 55.0 (5.2) | $51.0^{ab}$ (12.1) | $49.0^{ab}$ (15.5) | 3.8 | 5.7 | $13.6^{cd}$ |
| AL 201 | 42.0 | $35.0^{a}$ (16.7) | 33.0ab (21.4) | $32.0^{ab}$ (23.8) | 5.3 | 7.9 | $8.8^{cd}$ |
| C11 | 43.0 | $36.0^{a}$ (16.3) | $34.0^{ab}$ (20.9) | $32.0^{ab}$ (25.6) | 5.3 | 8.0 | $9.8^{cd}$ |
| Sarvodaya | 48.0 | 44.0 (8.3) | 44.0 (8.3) | $41.0^{a}$ (14.6) | 4.8 | 7.2 | NS |
| ICP 8859 | 58.0 | $55.0^{a}$ (5.2) | $53.0^{ab}$ (8.6) | $49.0^{ab}$ (15.5) | 2.6 | 3.9 | $25.6^{cd}$ |
| ICPL 89049 | 58.0 | 54.0 (6.9) | $50.0^{a}$ (13.8) | $48.0^{ab}$ (17.2) | 5.6 | 8.5 | $7.3^{e}$ |
| DPPA 85-13 | 60.0 | 58.0 (3.3) | 56.0 (6.7) | $51.0^{ab}$ (15.0) | 5.6 | 8.5 | NS |
| ICPL 89048 | 59.0 | 55.0 (6.8) | $50.0^{a}$ (15.3) | $48.0^{ab}$ (18.6) | 8.2 | 12.4 | NS |
| ICPL 87119 | 60.0 | 57.0 (5.0) | 55.0 (8.3) | $51.0^{ab}$ (15.0) | 6.2 | 9.3 | NS |
| AKT 8811 | 48.0 | $44.0^{ab}$ (8.3) | $43.0^{ab}$ (10.4) | $41.0^{ab}$ (14.6) | 3.5 | 5.2 | $8.6^{cd}$ |
| CO-6 | 39.0 | 34.0 (12.8) | $29.0^{ab}$ (25.6) | $26.0^{ab}$ (33.3) | 6.0 | 9.0 | $11.0^{cd}$ |
| GAUT 001E | 40.0 | $33.0^{ab}$ (17.5) | $31.0^{a}$ (22.5) | $29.0^{ab}$ (27.5) | 1.6 | 2.5 | $103.1^{cd}$ |
| GT 100 | 46.0 | 41.0 (10.9) | 42.0 (8.7) | $40.0^{a}$ (13.0) | 6.0 | 9.0 | NS |
| Pusa 84 | 45.0 | 42.0 (6.7) | $41.0^{a}$ (8.9) | $38.0^{ab}$ (15.6) | 3.8 | 5.7 | $7.0^{cd}$ |
| AWR 74/15 | 61.0 | 59.0 (3.3) | $57.0^{a}$ (6.6) | $52.0^{ab}$ (14.8) | 2.8 | 4.3 | $22.4^{cd}$ |
| ICP 8863 | 63.0 | $61.0^{ab}$ (3.2) | $58.0^{ab}$ (7.9) | $54.0^{ab}$ (14.3) | 1.2 | 1.7 | $138.0^{cd}$ |
| AL 15 | 42.0 | $37.0^{a}$ (11.9) | $34.0^{ab}$ (19.1) | $33.0^{ab}$ (21.4) | 4.1 | 6.2 | $11.2^{cd}$ |
| Pusa 855 | 41.0 | $32.0^{ab}$ (22.0) | $31.0^{ab}$ (24.4) | $29.0^{ab}$ (29.3) | 5.4 | 8.2 | $11.6^{cd}$ |
| Bahar | 63.0 | $56.0^{ab}$ (11.1) | 62.0 (1.6) | $50.0^{ab}$ (20.6) | 4.6 | 7.0 | $20.4^{cd}$ |
| GCP 33 | 59.0 | $56.0^{ab}$ (5.1) | $52.0^{ab}$ (11.9) | $50.0^{ab}$ (15.3) | 1.0 | 1.5 | $195.0^{cd}$ |
| Pusa 33 | 44.0 | $40.0^{ab}$ (9.1) | $39.0^{ab}$ (11.4) | $38.0^{ab}$ (13.6) | 1.0 | 1.5 | $83.0^{cd}$ |
| Paras | 43.0 | $38.0^{a}$ (11.6) | $38.0^{a}$ (11.6) | $36.0^{ab}$ (16.3) | 3.6 | 5.5 | $8.0^{cd}$ |
| CD $P \leq 0.05$ $P \leq 0.01$ | 4.5 6.1 | 4.0 5.4 | 4.0 5.3 | 3.3 4.5 | | | |
| *F*-value | $28.3^{cd}$ | $46.3^{cd}$ | $48.5^{cd}$ | $52.7^{cd}$ | | | |

Figures in parenthesis are percent decrease over control; [a]Significantly different from control at $P \leq 0.05$; [b]Significantly different from control at $P \leq 0.01$; [c]Significant at $P \leq 0.05$; [d]Significant at $P \leq 0.01$; NS = Not significant at $P \leq 0.05$

Table 36. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the functional nodule in pigeonpeain under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 38.0 | 33.00 (31.25) | 32.00 (33.35) | 26.00 (45.83) | 1.00 | 1.51 | 291.00 |
| Manak | 42.0 | 38.00 (9.52) | 36.00 (14.29) | 30.00 (28.57) | 9.57 | 14.45 | 3.26 |
| ICPL 87 | 35.0 | 29.00 (17.14) | 27.00 (22.86) | 23.00 (34.39) | 10.37 | 15.66 | 2.78 |
| ICP 14722 | 50.0 | 47.00 (6.00) | 41.00 (18.00) | 34.00 (32.00) | 6.98 | 10.55 | 12.24 |
| AL 201 | 34.0 | 26.00 (23.53) | 25.00 (26.47) | 21.00 (38.24) | 8.15 | 12.30 | 5.34 |
| C11 | 35.0 | 27.00 (22.86) | 26.00 (25.71) | 22.00 (37.41) | 7.17 | 10.83 | 6.89 |
| Sarvodaya | 43.0 | 39.00 (13.33) | 37.00 (17.78) | 31.00 (31.11) | 4.42 | 6.68 | 15.25 |
| ICP 8859 | 51.0 | 48.00 (5.88) | 43.00 (15.69) | 35.00 (31.37) | 5.64 | 8.52 | 18.34 |
| ICPL 89049 | 49.0 | 45.00 (8.16) | 38.00 (22.45) | 33.00 (32.65) | 6.39 | 9.65 | 14.90 |
| DPPA 85-13 | 54.0 | 52.00 (3.70) | 47.00 (12.96) | 39.00 (27.78) | 7.71 | 11.64 | 8.98 |
| ICPL 89048 | 50.0 | 46.00 (8.00) | 39.00 (22.00) | 34.00 (32.00) | 7.17 | 10.83 | 11.83 |
| ICPL 87119 | 53.0 | 50.00 (5.66) | 45.00 (15.06) | 37.00 (30.19) | 6.20 | 9.37 | 15.18 |
| AKT 8811 | 44.0 | 40.00 (9.09) | 39.00 (11.36) | 32.00 (27.27) | 4.71 | 7.12 | 13.39 |
| CO-6 | 37.0 | 21.00 (43.24) | 21.00 (43.24) | 17.00 (54.05) | 11.79 | 17.81 | 6.51 |
| GAUT 001E | 36.0 | 23.00 (36.11) | 23.00 (36.11) | 19.00 (47.22) | 6.59 | 9.96 | 14.44 |
| GT 100 | 40.0 | 35.00 (12.50) | 34.00 (15.00) | 28.00 (30.00) | 8.79 | 13.28 | 3.95 |
| Pusa 84 | 40.0 | 36.00 (10.00) | 34.00 (15.00) | 28.00 (30.00) | 8.46 | 12.78 | 4.17 |
| AWR 74/15 | 55.0 | 53.00 (3.64) | 48.00 (12.73) | 40.00 (27.27) | 5.25 | 7.93 | 19.37 |
| ICP 8863 | 57.0 | 55.00 (3.51) | 50.00 (12.28) | 42.00 (26.32) | 5.76 | 8.70 | 16.08 |
| AL 15 | 35.0 | 29.00 (17.14) | 27.00 (22.86) | 23.00 (34.29) | 8.46 | 12.78 | 4.17 |
| Pusa 855 | 32.0 | 23.00 (28.13) | 23.00 (28.13) | 19.00 (40.63) | 6.39 | 9.65 | 8.55 |
| Bahar | 57.0 | 40.00 (29.82) | 48.00 (15.79) | 33.00 (42.11) | 5.02 | 7.58 | 50.68 |
| GCP 33 | 51.0 | 48.00 (5.88) | 42.00 (17.65) | 35.00 (31.37) | 7.38 | 11.14 | 10.98 |
| Pusa 33 | 38.0 | 33.00 (13.16) | 32.00 (15.79) | 28.00 (26.32) | 5.37 | 8.11 | 7.00 |
| Paras | 37.0 | 31.00 (16.22) | 30.00 (18.92) | 25.00 (32.43) | 7.81 | 11.80 | 4.74 |
| CD $P \leq 0.05$ | 7.1 | 7.84 | 7.28 | 6.61 | | | |
| $P \leq 0.01$ | 11.4 | 11.77 | 10.65 | 9.79 | | | |
| *F*-value | 1.3 | 1.70 | 1.10 | 1.07 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

Table 37. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on non functional nodules in pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 6.00 | 7.00 (16.67) | 8.00 (33.33) | 11.00 (83.33) | 4.15 | 6.27 | 3.23 |
| Manak | 5.00 | 6.00 (20.00) | 7.00 (40.00) | 10.00 (100.00) | 8.15 | 12.30 | 0.84 |
| ICPL 87 | 7.00 | 9.00 (28.57) | 8.00 (14.29) | 10.00 (42.86) | 11.68 | 17.64 | 0.15 |
| ICP 14722 | 8.00 | 8.00 0.00 | 10.00 (25.00) | 15.00 (87.50) | 3.46 | 5.22 | 10.92 |
| AL 201 | 8.00 | 9.00 (12.50) | 8.00 0.00 | 11.00 (37.50) | 10.09 | 15.24 | 0.23 |
| C11 | 8.00 | 9.00 (12.50) | 8.00 0.00 | 10.00 (25.00) | 9.96 | 15.04 | 0.11 |
| Sarvodaya | 5.00 | 6.00 (20.00) | 7.00 (40.00) | 10.00 (100.00) | 4.78 | 7.23 | 2.57 |
| ICP 8859 | 7.00 | 5.00 (-28.57) | 10.00 (42.86) | 14.00 (100.00) | 6.39 | 9.65 | 4.24 |
| ICPL 89049 | 10.00 | 9.00 (-10.00) | 12.00 (20.00) | 15.00 (50.00) | 6.23 | 9.41 | 2.26 |
| DPPA 85-13 | 6.00 | 6.00 0.00 | 9.00 (50.00) | 12.00 (100.00) | 4.11 | 6.21 | 5.82 |
| ICPL 89048 | 9.00 | 9.00 0.00 | 11.00 (22.22) | 14.00 (55.56) | 3.26 | 4.92 | 6.28 |
| ICPL 87119 | 7.00 | 7.00 0.00 | 10.00 (42.86) | 14.00 (100.00) | 2.51 | 3.79 | 20.84 |
| AKT 8811 | 4.00 | 4.00 0.00 | 4.00 0.00 | 9.00 (125.00) | 4.42 | 6.68 | 3.81 |
| CO-6 | 9.00 | 13.00 (44.44) | 8.00 (-11.11) | 9.00 0.00 | 6.72 | 10.14 | 1.30 |
| GAUT 001E | 8.00 | 9.00 (12.50) | 8.00 0.00 | 10.00 (25.00) | 3.41 | 5.15 | 0.94 |
| GT 100 | 6.00 | 6.00 0.00 | 8.00 (33.33) | 12.00 (100.00) | 4.75 | 7.17 | 4.24 |
| Pusa 84 | 5.00 | 6.00 (20.00) | 7.00 (40.00) | 10.00 (100.00) | 7.53 | 11.38 | 0.98 |
| AWR 74/15 | 6.00 | 6.00 0.00 | 9.00 (50.00) | 12.00 (100.00) | 4.99 | 7.53 | 3.96 |
| ICP 8863 | 6.00 | 6.00 0.00 | 8.00 (33.33) | 12.00 (100.00) | 6.72 | 10.14 | 2.12 |
| AL 15 | 7.00 | 8.00 (14.29) | 8.00 (14.29) | 10.00 (42.86) | 7.88 | 11.90 | 0.30 |
| Pusa 855 | 9.00 | 9.00 0.00 | 8.00 (-11.11) | 10.00 (11.11) | 6.39 | 9.65 | 0.20 |
| Bahar | 6.00 | 16.00 (16.67) | 14.00 (133.33) | 17.00 (183.33) | 3.82 | 5.77 | 20.39 |
| GCP 33 | 8.00 | 8.00 0.00 | 10.00 (25.00) | 15.00 (87.50) | 6.79 | 10.26 | 2.83 |
| Pusa 33 | 6.00 | 7.00 (16.67) | 7.00 (16.67) | 10.00 (66.67) | 5.37 | 8.11 | 1.24 |
| Paras | 6.00 | 7.00 (16.67) | 8.00 (33.33) | 11.00 (83.33) | 9.77 | 14.76 | 0.58 |
| CD $P \leq 0.05$ | 1.86 | 2.86 | 2.48 | 2.82 | | | |
| $P \leq 0.01$ | 2.94 | 4.75 | 3.75 | 4.68 | | | |
| *F*-value | 1.63 | 1.32 | 1.10 | 1.06 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

201, C 11, ICP 8859, AL 15 and Paras $P \leq 0.05$) in comparison to the control. The nodulation was also inhibited in the pigeonpea plants grown in root-knot nematode infested plots. Greatest reduction in functional nodules was observed in CO-6 (48.6%) whereas it was lowest in AWR 74/15 (6.6%). A significant decrease in the number of functional nodules and increase in non functional nodules due to root-knot infection was observed in the cvs. UPAS 120, ICPL 89049, ICPL 89048, CO-6, GAUT 001E, Pusa 855, Bahar ($P \leq 0.01$) and ICP 14722, AL 201, C 11, Sarvodaya, ICP 8859, ICPL 87119,AKT 8811, AWR 74/15, ICP 8863, GCP 33, Pusa 33 ($P \leq 0.05$) (Table 36 and 37).

Concomitant inoculation with *F. udum* and *M. incognita* caused greater decrease in the nodulation in the pigeonpea cultivars. Greatest suppression in total and functional nodules was observed in CO-6 (33.3% and 64.9% respectively) and least affected cultivar was ICP 8863 where 26.3% reduction in functional nodules was observed.

**4.6.5 Soil population of pathogens**

Soil population of juveniles of *M. incognita* gradually and significantly increased during the crop season in comparison to planting population. Greatest increase in the population of the nematode was noticed in the cv. CO-6 (92%) followed by Pusa 855 (91.1%) whereas minimum increase was recorded in AKT 8811(26.5%) ICP 8863 (27.2%) and AWR 74/15 (28.2%) (Table 38). In concomitantly inoculated plots, the soil population of *M. incognita* decreased significantly ($P \leq 0.01$) in comparison to the nematode population in the absence of wilt fungus (Table 38). Greatest suppression in the nematode population was recorded in GT 100 (18.1%) whereas it was lowest in ICP 8863 (8.6%).

The soil population of *F. udum* increased during mid season of cropping but gradually decreased at harvesting time (Table 39). It was observed that in the presence of *M. incognita* soil population of *F. udum* increased the highest increase in soil population of *F. udum* during mid seasone of cropping was observed in cv. Bahar where it was 3.2 x $10^{10}$ and 4.8 x $10^{10}$ $CFU_s$ /g in the micro plots which was inoculated with *F. udum* and *F. udum* + *M. incognita,* respectively. However, at harvesting time the population of *F. udum* gradually decreased to 2.6 x $10^8$ and 2.9 x $10^8$ $CFU_s$ /g in the micro plots inoculated with *F. udum* and *F. udum* + *M. incognita,* respectively. The lowest increase in soil population of *F. udum* during mid season of cropping was recorded in cv. ICP8863 which was 8 x $10^9$ and 1.1 x $10^{10}$ $CFU_s$ /g in the micro plots inoculated with *F. udum* and *F. udum* + *M. incognita,* respectively. At harvest the population of *F. udum* was also lowest in cv.

Table 38. Effect of *Fusarium udum* and *Meloidogyne incognita* singly and concomitantly on the soil population of root-knot nematodes in pigeonpea under field condition

| Cultivars | Control | *Fusarium udum* $20x10^8$ CFUs/g soil | *Meloidogyne incognita* 2000 $J_2$/kg soil | *F. udum* + *M. incognita* | CD | | *F*-value |
|---|---|---|---|---|---|---|---|
| | | | | | $P \leq 0.05$ | $P \leq 0.01$ | |
| UPAS 120 | 0.00 | 0.00 | 1670 | 1150.00 (31.14) | 118.98 | 179.71 | 597.06 |
| Manak | 0.00 | 0.00 | 1615.00 | 1073.00 (33.56) | 72.01 | 108.77 | 1499.30 |
| ICPL 87 | 0.00 | 0.00 | 1760.00 | 1225.00 (30.40) | 89.37 | 134.98 | 1181.59 |
| ICP 14722 | 0.00 | 0.00 | 1680.00 | 1160.00 (30.95) | 180.67 | 272.88 | 262.39 |
| AL 201 | 0.00 | 0.00 | 1785.00 | 1252.00 (29.86) | 109.51 | 165.39 | 812.62 |
| C11 | 0.00 | 0.00 | 1760.00 | 1240.00 (29.55) | 200.74 | 303.19 | 235.62 |
| Sarvodaya | 0.00 | 0.00 | 1590.00 | 1069.00 (32.77) | 78.40 | 118.41 | 1232.70 |
| ICP 8859 | 0.00 | 0.00 | 1645.00 | 1120.00 (31.91) | 157.42 | 237.76 | 329.18 |
| ICPL 89049 | 0.00 | 0.00 | 1730.00 | 1198.00 (30.75) | 79.12 | 119.49 | 1453.13 |
| DPPA 85-13 | 0.00 | 0.00 | 1590.00 | 1057.00 (33.52) | 84.47 | 127.58 | 1056.55 |
| ICPL 89048 | 0.00 | 0.00 | 1720.00 | 1190.00 (30.81) | 85.23 | 128.73 | 1237.03 |
| ICPL 87119 | 0.00 | 0.00 | 1625.00 | 1093.00 (32.74) | 126.76 | 191.45 | 492.65 |
| AKT 8811 | 0.00 | 0.00 | 1530.00 | 1010.00 (33.99) | 116.34 | 175.71 | 514.15 |
| CO-6 | 0.00 | 0.00 | 1840.00 | 1310.00 (28.80) | 52.08 | 78.65 | 3847.45 |
| GAUT 001E | 0.00 | 0.00 | 1788.00 | 1270.00 (28.97) | 64.78 | 97.84 | 2344.80 |
| GT 100 | 0.00 | 0.00 | 1670.00 | 1138.00 (31.86) | 81.18 | 122.61 | 1276.12 |
| Pusa 84 | 0.00 | 0.00 | 1625.00 | 1088.00 (33.05) | 181.65 | 274.36 | 239.39 |
| AWR 74/15 | 0.00 | 0.00 | 1565.00 | 1040.00 (33.55) | 177.03 | 267.38 | 232.99 |
| ICP 8863 | 0.00 | 0.00 | 1545.00 | 1025.00 (33.66) | 141.17 | 213.22 | 356.83 |
| AL 15 | 0.00 | 0.00 | 1748.00 | 1210.00 (30.78) | 88.31 | 133.37 | 1190.59 |
| Pusa 855 | 0.00 | 0.00 | 1822.00 | 1290.00 (29.20) | 105.43 | 159.24 | 917.74 |
| Bahar | 0.00 | 0.00 | 1795.00 | 995.00 (44.57) | 40.32 | 60.89 | 5549.45 |
| GCP 33 | 0.00 | 0.00 | 1680.00 | 1160.00 (30.95) | 91.57 | 138.30 | 1021.53 |
| Pusa 33 | 0.00 | 0.00 | 1690.00 | 1173.00 (30.95) | 54.60 | 82.47 | 2914.34 |
| Paras | 0.00 | 0.00 | 1690.00 | 1179.00 (30.24) | 64.35 | 97.20 | 2103.51 |
| CD $P \leq 0.05$ | | | 77.11 | 94.44 | | | |
| $P \leq 0.01$ | | | 105.04 | 159.90 | | | |
| *F*-value | | | 1.70 | 0.96 | | | |

Figures in parenthesis are percentage decrease over control

[a]Significantly different from control at $P \leq 0.05$

[b]Significantly different from control at $P \leq 0.01$

[c]Significant at $P \leq 0.05$

[d]Significant at $P \leq 0.01$

ICP8863 among the all cultivars as it was 5.33 x $10^7$ and 5.34 x $10^7$ in the micro plots inoculated with *F. udum* and *F. udum* + *M. incognita*, respectively.

# Chapter-5

# DISCUSSION

## Experiment 1

### 5.1 Pot trial

#### 5.1.1 Interaction of root-knot nematode *Meloidogyne incognita* and wilt fungus *Fusarium udum* on pigeonpea germplasm.

Plants grown under pot condition where soil inoculation of *F. udum* was done expressed wilt symptoms. The wilt severity was found increased when *M. incognita* was present along with *F. udum* . this has been confirmed by some research workers earlier that severity of wilt disease increase when both the pathogens i.e. wilt fungus and root-knot nematode is present together (Askary *et al.,* 2005; Perveen *et al.* 1999). Some cultivars ICP 8863, AWR 74/15, ICP 8859, ICP 87119, ICP 89048, ICP 89049, GCP 33, ICP 14722, DPPA 85-13 expressed a very least effect of wilt fungus *F. udum* on wilt disease. This confirms that these cultivars are resistance or tolerance to *F. udum*. However in presence of *M. incognita* the wilting was expressed by these cultivars. This confirms that nematodes are breaking the wilt resistant or tolerance capacity of plants (Upadhayay and Dwivedi, 1987b; Dwivedi *et al.* 1992). As the inoculum level of nematodes was increased the number of galls per root system increased in all the cultivars. No cultivars were found resistant to *M. incognita*. In presence of *F. udum* with *M. incognita* the number of galls per root system decreased. This may be due to *F. udum* which colonized the internal root system of plants thereby providing lesser opportunity to *M. incognita* to multiply and reproduce (Dwivedi and Upadhayay, 1988; Dwivedi *et al.* 1992). The egg mass per root system also become less when *F. udum* was present with *M. incognita*. This was also caused by *F. udum* in the internal root system of plant. The dry weight of plant decreased when *F. udum* and *M. incognita* was applied in the soil alone. However some cvs. ICP 8863, AWR 74/15, DPPA 85-13, ICP 89049, ICP 8859 and ICP 14722 showed no significant effect upon dry weight of plant in the presence of *F. udum* alone. This may be due to resistant capacity of these cultivars to wilt fungus *F. udum*. However in presence of *M. incognita* and *F. udum* concomitantly, the dry weight of plant decreased in all the cultivars of pigeonpea tested. This may be due to *M. incognita* which breaks the *F. udum* resistance in plants (Upadhayay and Dwivedi, 1987b; Dwivedi *et al.* 1992). The yield (grain weight per plant) suppressed the most when both *F. udum* and *M. incognita* was

Table 39.Rhizoshpere population (CFUs) of *Fusarium udum* singly and concomitantly with *Meloidogyne incognita* under field condition.

| Cultivar | At sowing | | Mid season | | Harvesting | |
|---|---|---|---|---|---|---|
| | *F. udum* | *F. udum+ M.Incognita* | *F. udum* | *F. udum+ M. Incognita* | *F. udum* | *F. udum+ M.incognita* |
| UPAS 120 | $2.00X10^8$ | $2.00X10^8$ | $2.72X10^{10}$ | $4.01X10^{10}$ | $2.15X10^8$ | $2.35X10^8$ |
| Manak | $2.00X10^8$ | $2.00X10^8$ | $2.82X10^{10}$ | $4.15X10^{10}$ | $2.23X10^8$ | $2.42X10^8$ |
| ICPL 87 | $2.00X10^8$ | $2.00X10^8$ | $3.10X10^{10}$ | $4.58X10^{10}$ | $2.45X10^8$ | $2.68X10^8$ |
| ICP 14722 | $2.00X10^8$ | $2.00X10^8$ | $1.07X10^{10}$ | $1.54X10^{10}$ | $2.39X10^8$ | $2.61X10^8$ |
| AL 201 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $4.56X10^{10}$ | $2.43X10^8$ | $2.65X10^8$ |
| C11 | $2.00X10^8$ | $2.00X10^8$ | $3.06X10^{10}$ | $4.51X10^{10}$ | $2.41X10^8$ | $2.63X10^8$ |
| Sarvodaya | $2.00X10^8$ | $2.00X10^8$ | $2.88X10^{10}$ | $4.24X10^{10}$ | $2.27X10^8$ | $2.47X10^8$ |
| ICP 8859 | $2.00X10^8$ | $2.00X10^8$ | $1.06X10^{10}$ | $1.49X10^{10}$ | $7.77X10^7$ | $8.03X10^7$ |
| ICPL 89049 | $2.00X10^8$ | $2.00X10^8$ | $9.60X10^9$ | $1.37X10^{10}$ | $7.02X10^7$ | $7.11X10^7$ |
| DPPA 85-13 | $2.00X10^8$ | $2.00X10^8$ | $9.92X10^9$ | $1.41X10^{10}$ | $7.28X10^7$ | $7.40X10^7$ |
| ICPL 89048 | $2.00X10^8$ | $2.00X10^8$ | $9.54X10^9$ | $1.34X10^{10}$ | $6.89X10^7$ | $6.96X10^7$ |
| ICPL 87119 | $2.00X10^8$ | $2.00X10^8$ | $1.01X10^{10}$ | $1.44X10^{10}$ | $7.46X10^7$ | $7.69X10^7$ |
| AKT 8811 | $2.00X10^8$ | $2.00X10^8$ | $2.70X10^{10}$ | $3.97X10^{10}$ | $2.11X10^8$ | $2.30X10^8$ |
| CO-6 | $2.00X10^8$ | $2.00X10^8$ | $3.09X10^{10}$ | $4.55X10^{10}$ | $2.43X10^8$ | $2.65X10^8$ |
| GAUT 001E | $2.00X10^8$ | $2.00X10^8$ | $3.06X10^{10}$ | $4.54X10^{10}$ | $2.42X10^8$ | $2.63X10^8$ |
| GT 100 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $4.57X10^{10}$ | $2.43X10^8$ | $2.65X10^8$ |
| Pusa 84 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $4.61X10^{10}$ | $2.46X10^8$ | $2.69X10^8$ |
| AWR 74/15 | $2.00X10^8$ | $2.00X10^8$ | $9.60X10^9$ | $1.34X10^{10}$ | $6.50X10^7$ | $6.53X10^7$ |
| ICP 8863 | $2.00X10^8$ | $2.00X10^8$ | $8.00X10^9$ | $1.10X10^{10}$ | $5.33X10^7$ | $5.34X10^7$ |
| AL 15 | $2.00X10^8$ | $2.00X10^8$ | $3.08X10^{10}$ | $4.56X10^{10}$ | $2.43X10^8$ | $2.65X10^8$ |
| Pusa 855 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $4.58X10^{10}$ | $2.44X10^8$ | $2.67X10^8$ |
| Bahar | $2.00X10^8$ | $2.00X10^8$ | $3.20X10^{10}$ | $4.80X10^{10}$ | $2.60X10^8$ | $2.90X10^8$ |
| GCP 33 | $2.00X10^8$ | $2.00X10^8$ | $1.06X10^{10}$ | $1.49X10^{10}$ | $8.06X10^7$ | $8.27X10^7$ |
| Pusa 33 | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $4.51X10^{10}$ | $2.44X10^8$ | $2.68X10^8$ |
| Paras | $2.00X10^8$ | $2.00X10^8$ | $3.07X10^{10}$ | $4.55X10^{10}$ | $2.46X10^8$ | $2.70X10^8$ |

present together in soil than either of the pathogen alone. However less effected cultivars were ICP8863 and AWR 74/15 among all the cultivars used in the study.

A decrease in the root nodulation of plant was recorded in presence of *F. udum* and *M. incognita* in all the cultivars tested. The functional roon nodules decreased and non functional root nodules increased the most when both *F. udum* and *M. incognita* was simultaneously present in soil. Increase in inoculum level of *F. udum* or *M. incognita* resulted in a decrease in the root nodulation of plant in all the cultivars. This confirms the report of earlier research workers (Perveen *et al.* 1999; Haseeb *et al.,* 2005). Number of soil population of *M. incognita* increased with the increase in initial inoculum level of the pathogen. However the percent increase wasless at 500 level followed by 1000 and 2000 $J_2$ in soil. Presence of *F. udum* with *M. incognita* suppress the final population of juveniles of *M. incognita* in soil. *F. udum* population (CFUs / g) in soil was maximum during mid season of cropping but decreased at harvesting time. The soil population of *F. udum* increased in presence of *M. incognita* than *F. udum* alone at both mid season of cropping and at harvest.

## Experiment 2

### 5.2 Effect of seeds treatment with different materials on the interaction of root-knot nematode *Meloidogyne incognita* and wilt fungus *Fusarium udum* on pigeonpea cv. UPAS 120 under pot condition.

The wilt severity in plants grown from untreated seeds was higher than the treated seeds. Use of dimethoate as seed treatment showed no significant effect on wilting of the plants. Neem seed powder alone and in combination with *C. procera* reduced the wilt severity in plants grown in the soil treated with *F. udum* alone and in combination with *M. incognita*. This confirms the report of earlier workers (Kotasthane *et al.*, 1987; Mishra, 1986; Mojumder and Mishra, 1991 and 1993; Mahalinga *et al.,* 2003). The root galls and egg masses per root system also suppressed n the plants grown from the treated seeds. Seed treatment with neem seed powder, Dimethoate, *C. procera* has a suppressive effect on root nematode multiplication (Mishra, 1986; Chakrabarti and Mishra, 2001; Mojumder and Mishra, 1991 and 1993). The treatment was most effective when Dimethoate was combined with neem seed powder and *C. procera.*

The dry weight decreased in plants grown from untreated seeds. The decrease in dry weight of plant was maximum when grown in the soil inoculated with *M. incognita* +

found most susceptible to wilt fungus *F. udum* as compared to other cultivars of pigeonpea used in the study. The cvs. ICP 8863 and AWR 74/15 was least affected when *F. udum* alone was applied in the soil. However, these two cultivars also become susceptible when both the pathogens were used concomitantly in the soil. This confirms that in the presence of root-knot nematodes the resistance capacity to *F. udum* break in plants (Upadhayay and Dwivedi, 1987b).

Number of root galls and egg mass per root system was maximum when *M. incognita* alone was inoculated in soil. However, in combination with *F. udum* the number of root galls and the egg mass per root system decreased which confirms that *F. udum* has suppressive effect on nematode multiplication. The galls and egg mass per root system was least in cv. ICP 8863 where as it was highest in CO6 and Pusa 855. Dry weight of plant and yield per micro plot was decreased the maximum when both the pathogens were applied simultaneously than either of the pathogen alone. The loss in yield was severe when both the pathogens were simultaneously present in soil (Singh *et al.*, 2004). The most effect pigeonpea cultivar was Bahar and the least affected were cvs. ICP 8863 and AWR 74/15. These two cultivars (ICP 8863 and AWR 74/15) showed the least effect on yield when *F. udum* alone was applied in soil. Decrease in functional root nodules and increase in non functional nodules were recorded in all the cultivars of pigeonpea used in the study where soil inoculation was done with *F. udum* and *M., incognita.* In cvs. ICP8863, AWR 74/15, GCP 33, ICPL 87119, ICPL 8748, DPPA 85-13, ICP 89049, ICP 8859, ICP 14722 and AKT 8811 showed a very less effect on root nodulation when either of the pathogen i.e. *F. udum* and *M. incognta* alone was applied in the soil. However decrease in total and functional root nodules and increase in non functional root nodules was greater when both the pathogens were applied in soil concomitantly in all the cultivars. This confirms the earlier report that suppressive affect on root nodulation by *M. incognita* increase when combined with wilt fungus (Perveen *et al.*, 1999). Final soil population of juveniles of *M. incognita* increased in all the micro plots over initial inoculum level. The maximum increase was found in the microplots where cvs. CO6 and Pusa 855 were grown whereas minimum population of *M. incognita* was found in the micro plots of ICP 8863 and AWR 74/15. In presence of wilt fungus *F. udum* the soil population of juveniles of *M. incognita* decreased in the all the cultivars. Soil population of *F. udum* was highest during cropping season but a gradual decrease in soil population of *F. udum* was observed at harvest time in all the microplots where pathogens were

inoculated. Maximum increase in *F. udum* population was observed in cv. Bahar whereas it was minimum in cvs.ICP 8863 and AWR 74/15. These two cvs. (ICP 8863 and AWR 74/15) showed the least effect of *F. udum* and *M, incognita* either singly or in combination on all the parameters studied.

*F. udum* followed by either of the pathogen alone (Upadhayay and Dwivedi, 1987; Perveen *et al.* 1999). Grain weight per plant decreased the most when both the pathogens were simultaneously present in the soil than either of the pathogen alone. Among all the seed treatments used the best combination was Domethoate + Neem seed powder + *C. procera* where the loss in grain weight per plant was very less followed by *C. procera* + Neem seed powder. Therefore, these two combination of seed treatments proved successful in the management of nematode-fungus disease complex. Decrease in functional root nodules and increase in non functional root nodule per root system was highest in plants grown from untreated seeds in the soil inoculated with *F. udum* + *M. incognita* simultaneously than either of the pathogen alone. The best seed treatment which showed the minimum effect of *F. udum* and *M. incognita* upon root nodulation was Dimethoate + Neem seed powder+ *C. procera* followed by *C. procera* + Neem seed powder. The effect of *C. procera* and neem seed powder upon rooot nodulation has also been confirmed by Mojumder and Mishra, 1991.

Soil population of juveniles of *M. incognita* decreased where seed treatment was done with Dimethoate + Neem seed powder + *C. procera* followed by *C. procera* + Neem seed powder. The less effective seed treatment was Dimethoate followed by *C. procera* and Neem seed powder alone. Soil population of *F. udum* (CFUs / g) was maximum during mid season of cropping but gradually decreased at harvest. The soil population of *F. udum* was almost not affected when Dimethoate alone was used as seed treatment. The suppression in soil population of *F. udum* was maximum when Dimethoate in combination with *C. procera* and Neem seed powder was used as seed treatment. The suppressive effect of Neem seed powder on *F. udum* has also been reported by some workers (Mahalinga *et al.,* 2003; Bharathi *et al.* 2006).

## Experiment 3

### 5.3 Field trial

### 5.3.1 To study the single and interactive pathogenic effects of root-knot nematode *Meloidogyne incognita* and wilt fungus *Fusarium udum* on pigeonpea germplasm under pot and field condition.

In the field condition the wilt severity was maximum in Bahar when soil inoculation was done with *F. udum*, however, the severity of the disease increased when *F. udum* was concomitantly applied in the soil with *M. incognita*. The cv. Bahar was

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## SUMMARY

Plants grown under pot condition where soil inoculation of *F. udum* was done expressed wilt symptoms. The wilt severity was found increased when *M. incognita* was present along with *F. udum*. Some cultivars ICP 8863, AWR 74/15, ICP 8859, ICP 87119, ICP 89048, ICP 89049, GCP 33, ICP 14722, DPPA 85-13 expressed lesser effect of wilt fungus *F. udum* on wilt disease as compared to other cultivars used in the study. *F. udum* when combined with *M. incognita* the number of galls per root system decreased. The dry weight of plant decreased when *F. udum* and *M. incognita* was applied in the soil singly or concomitantly. Some cvs. ICP 8863, AWR 74/15, DPPA 85-13, ICP 89049, ICP 8859 and ICP 14722 showed no significant effect upon dry weight of plant in the presence of *F. udum* alone. A decrease in the root nodulation of plant was recorded in presence of *F. udum* and *M. incognita* in all the cultivars tested. The functional root nodules decreased and non functional root nodules increased the most when both *F. udum* and *M. incognita* was simultaneously present in soil. Increase in inoculum level of *F. udum* or *M. incognita* resulted in a decrease in the root nodulation of plant in all the cultivars. Number of soil population of juveniles of *M. incognita* increased with the increase in initial inoculum level. Presence of *F. udum* along with *M. incognita* suppressed the final population of juveniles of *M. incognita* in soil. The soil population of *F. udum* increased in presence of *M. incognita* than *F. udum* alone at both mid season of cropping and at harvest.

In case of field trial number of root galls and egg mass per root system was highest in all the cultivars, when *M. incognita* alone was inoculated in soil. However, in combination with *F. udum* the number of root galls and the egg mass per root system decreased which confirms that *F. udum* has suppressive effect on nematode multiplication. In presence of wilt fungus, *F. udum* the soil population of juveniles of *M. incognita* decreased in the all the cultivars. Maximum increase in *F. udum* population was observed in cv. Bahar whereas it was minimum in cvs.ICP 8863 and AWR 74/15.

Seed treatment with neem seed powder alone and in combination with *C. procera* reduced the wilt severity in plants grown in the soil inoculated with *F. udum* alone and in combination with *M. incognita*. The root galls and egg masses per root system was suppressed in the plants grown from the treated seeds. The dry weight decreased in plants grown from untreated seeds where soil inoculation was done with *F. udum* and *M.*

*incognita* singly or concomitantly. The decrease in dry weight of plant grown from untreated seeds was maximum in the soil inoculated with *M. incognita* + *F. udum* followed by either of the pathogen alone. Decrease in functional root nodules and increase in non functional root nodule per root system was highest in plants grown from untreated seeds in the soil inoculated with *F. udum* + *M. incognita* simultaneously than either of the pathogen alone. The best seed treatment which showed the minimum effect of *F. udum* and *M. incognita* upon root nodulation was Dimethoate + Neem seed powder+ *C. procera* followed by *C. procera* + Neem seed powder. Soil population of juveniles of *M. incognita* decreased where seed treatment was done with Dimethoate + Neem seed powder + *C. procera* followed by *C. procera* + Neem seed powder. The soil population of *F. udum* was least affected when Dimethoate alone was used as seed treatment. The suppression in soil population of *F. udum* was maximum when Dimethoate in combination with *C. procera* and Neem seed powder was used as seed treatment.

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# ABSTRACT

Plants grown under pot condition where soil inoculation of *F. udum* was done expressed wilt symptoms. Some cultivars ICP 8863, AWR 74/15, ICP 8859, ICP 87119, ICP 89048, ICP 89049, GCP 33, ICP 14722, DPPA 85-13 expressed lesser effect of wilt fungus *F. udum* on wilt disease as compared to other cultivars used in the study. *F. udum* when combined with *M. incognita* the number of galls per root system decreased. The dry weight of plant decreased when *F. udum* and *M. incognita* was applied in the soil singly or concomitantly. The functional root nodules decreased and non functional root nodules increased the most when both *F. udum* and *M. incognita* was simultaneously present in soil. Number of soil population of juveniles of *M. incognita* increased with the increase in initial inoculum level. Presence of *F. udum* along with *M. incognita* suppressed the final population of juveniles of *M. incognita* in soil. In presence of wilt fungus, *F. udum* the soil population of juveniles of *M. incognita* decreased in the all the cultivars. The root galls and egg masses per root system was suppressed in the plants grown from the treated seeds. The dry weight decreased in plants grown from untreated seeds where soil inoculation was done with *F. udum* and *M. incognita* singly or concomitantly. Decrease in functional root nodules and increase in non functional root nodule per root system was highest in plants grown from untreated seeds in the soil inoculated with *F. udum* + *M. incognita* simultaneously than either of the pathogen alone. The best seed treatment which showed the minimum effect of *F. udum* and *M. incognita* upon root nodulation was Dimethoate + Neem seed powder+ *C. procera* followed by *C. procera* + Neem seed powder. Soil population of juveniles of *M. incognita* decreased where seed treatment was done with Dimethoate + Neem seed powder + *C. procera* followed by *C. procera* + Neem seed powder.